KATMAI NATIONAL PARK AND PRESERVE,

ALASKA

WATER RESOURCES SCOPING REPORT

Don P. Weeks

Technical Report NPS/NRWRD/NRTR-99/226

WATER RESOURCES DIVISION

National Park Service - Department of the Interior
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September, 1999

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United States Department of the Interior
National Park Service

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EXECUTIVE SUMMARY

Katmai National Park and Preserve (KATM) and the Alagnak Wild River, which is managed by KATM, lie in a hydrologically complex environment in southwestern Alaska that has evolved around several volcanic and glacial events. The park includes the largest freshwater lake (228 mi^2) and one of the longest continuous segments of marine coast (398 miles) in the National Park system, including an intricate network of streams, wetlands, and smaller lakes. Healthy water resources play an important role in the success of KATM's diverse biota. The park's waters support significant sockeye salmon (*O. nerka*) spawning habitat upon which the Bristol Bay commercial salmon fishery, the largest in the world, and the regional economy depend.

The National Park Service (NPS) is aware of both widespread and local threats, which have the potential to degrade KATM's water resources. This, along with the lack of basic baseline water resource information, led the park to request assistance from the NPS Water Resources Division (WRD) to prepare this Water Resources Scoping Report (WRSR).

This report identifies and briefly describes the natural resources at KATM, which includes the Alagnak Wild River and the surrounding area, and the significant water-related issues that park management is challenged to address. The report also summarizes the park's existing natural resources program to evaluate current staffing and natural resource management projects and to identify some of the park's management needs.

In certain cases, WRSRs meet the current water management needs for NPS units, where the number and complexity of issues are minimal. In such cases, park Resource Management Plan (RMP) project statements are included in the report to provide NPS management with the necessary action plan(s) to address the high-priority issues.

For KATM, several water-related issues exist, including the extensive environmental damage that resulted from the 1989 *Exxon Valdez* oil spill. Many of the issues presented in this report center around the lack of basic information (i.e., baseline data) that would better assist the NPS's understanding of KATM's water resources. Thus, the NPS may be unaware of significant and/or time-sensitive issues because the natural resource information is not available.

The contents of this report are limited to information made available to the author during the time this report was prepared. Where appropriate, issue-specific recommendation(s) previously proposed by NPS management via KATM planning documents (i.e., RMP) are included. As a result, descriptions of the natural resources and water resource issues vary in detail, and inclusion of issue-related recommendations is inconsistent.

As part of the effort by the NPS WRD to produce this report for KATM, WRD staff traveled to Anchorage and KATM in 1998. The purposes of this travel were to: 1) introduce elements of the WRSR effort to KATM, NPS-Alaska System Support Office, and U.S. Geological Survey (USGS) staff, 2) become familiar with the water resources and high priority water-related issues at the park, 3) obtain pertinent information from park and other agency files, and 4) establish contacts with federal and state personnel and others with expertise on water resources in the region. The high priority issues identified at KATM during this effort include:

- Baseline Inventory and Monitoring
- Climate Change and Influences on Water Resources
- Nutrient Cycling
- American Creek Streambed Disturbance
- Alagnak Wild River Bank Erosion by Boat Traffic
- Water Resource Impacts from Backcountry Facilities
- *Exxon Valdez* 1989 Oil Spill
- Potential Oil/Gas Leasing in Lower Cook Inlet and Shelikof Strait
- Brooks Camp Petroleum Contamination
- Brooks Camp Wastewater Management
- Valley Road Management
- Wetlands Management
- Spill Contingency Planning
- Water Rights
- Coordination

Each of these issues has aspects that affect the park's water resources, though some may not be under NPS control; therefore, it is important to recognize the fact that multi-agency communication and coordination are essential to successfully manage KATM's watershed. Based on the assessment of these issues, a recommendation and justification to produce a more comprehensive Water Resources Management Plan (WRMP) for KATM is presented at the end of this report. The WRMP process encourages other stakeholders to participate with the NPS during and after plan development. This process, if carried through, will produce regional ownership of the WRMP, which is needed to effectively drive the plan's recommended actions.

INTRODUCTION

Katmai National Park and Preserve (KATM) encompasses about 6,500 square miles (3.6 million acres) of public lands near the north end of the Alaska Peninsula in southwestern Alaska. Approximately 432,000 acres (12%) of this park unit is occupied by surface water. An additional 216,000 acres (6%) is made up of glaciers (U.S. National Park Service, 1994). KATM includes the largest freshwater lake, Naknek Lake, and one of the longest continuous segments of marine coast (398 miles) in the National Park system. Jean Bodeau (1992) captures the complex and diverse environments of KATM in her book *Katmai National Park and Preserve, Alaska*:

> "It is a lasagna of overlapping contrasting worlds, layered in time and character. The fiery volcanos of the Aleutian Range erupt through the crevassed blue of glacier ice. The Alaska Peninsula, southwestern stub of the vast interior of Alaska, and the rugged giants of the Alaska Range give way to the Aleutian island chain. Descending to the north, the volcanos flatten into the largest system of lakes and rivers in the national park system before reaching the salmon-rich waters of Bristol Bay. To the south, they plunge to the rugged coastline of the cold and stormy Shelikof Strait."

It is important for the NPS to differentiate between natural versus anthropogenic-impacted environments so that mandated management is appropriately implemented toward the park's water resources. This can be a challenge at KATM. For example, a stream void of biological diversity may be the result of natural volcanic influences and not a man-induced impact; thus, the NPS would seek to maintain this natural condition.

The objective of this report is to provide NPS management with a brief overview of KATM's diverse environments, existing water-related information and issues that pertain to KATM, while also identifying some of the "information needs" that will better assist NPS management in providing a greater level of water resource protection. Since the Alagnak Wild River is under KATM management and drains two large lakes in the park (Kukaklek and Nonvianuk lakes), water-related issues for this NPS unit are also included in the report. At the end of the report, an evaluation of this information is presented to determine if a more comprehensive Water Resources Management Plan (WRMP) is warranted for this NPS unit.

The initial information-gathering effort for this report was a 10-day visit by the author to Anchorage and KATM. Information was derived from many sources, including interviews with park management and other Federal and State agencies (i.e., U.S. Geological Survey, Alaska Department of Environmental Conservation, etc.), and reviews of existing natural resources information with emphasis on water resources. The author was also fortunate to visit many of the remote sites in KATM (i.e., Brooks Camp, Valley of Ten Thousand Smokes, Shelikof Strait coast, etc.), which provided a better appreciation of the diverse water resources and associated issues.

Location, Legislation, and Management

KATM is located approximately 300 miles southwest of Anchorage (Figure 1). It is bounded to the east by the Shelikof Strait on the Gulf of Alaska. The north boundary follows the divide between Nonvianuk/Alagnak drainage and the Kvichak/Iliamna drainage. The west boundary is a moraine west of Naknek Lake and the southwest boundary encompasses the headwaters of the King Salmon River and Kejulik River (Figure 2) (U.S. National Park Service, 1994).

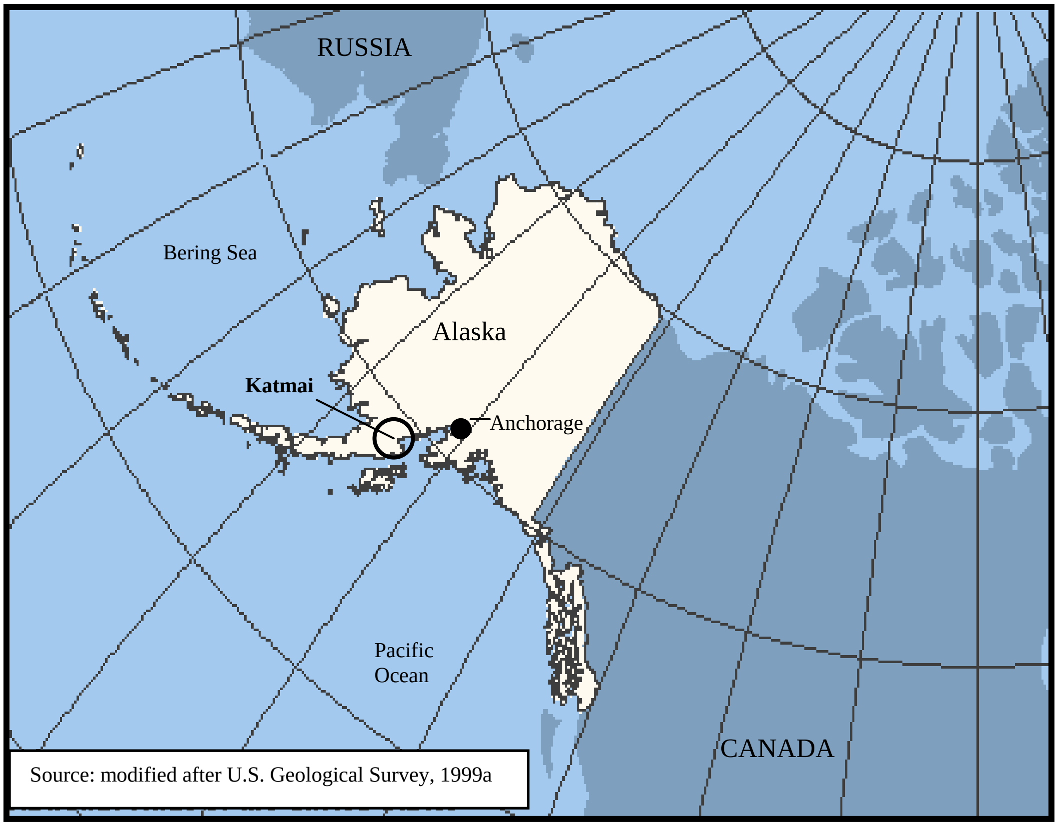
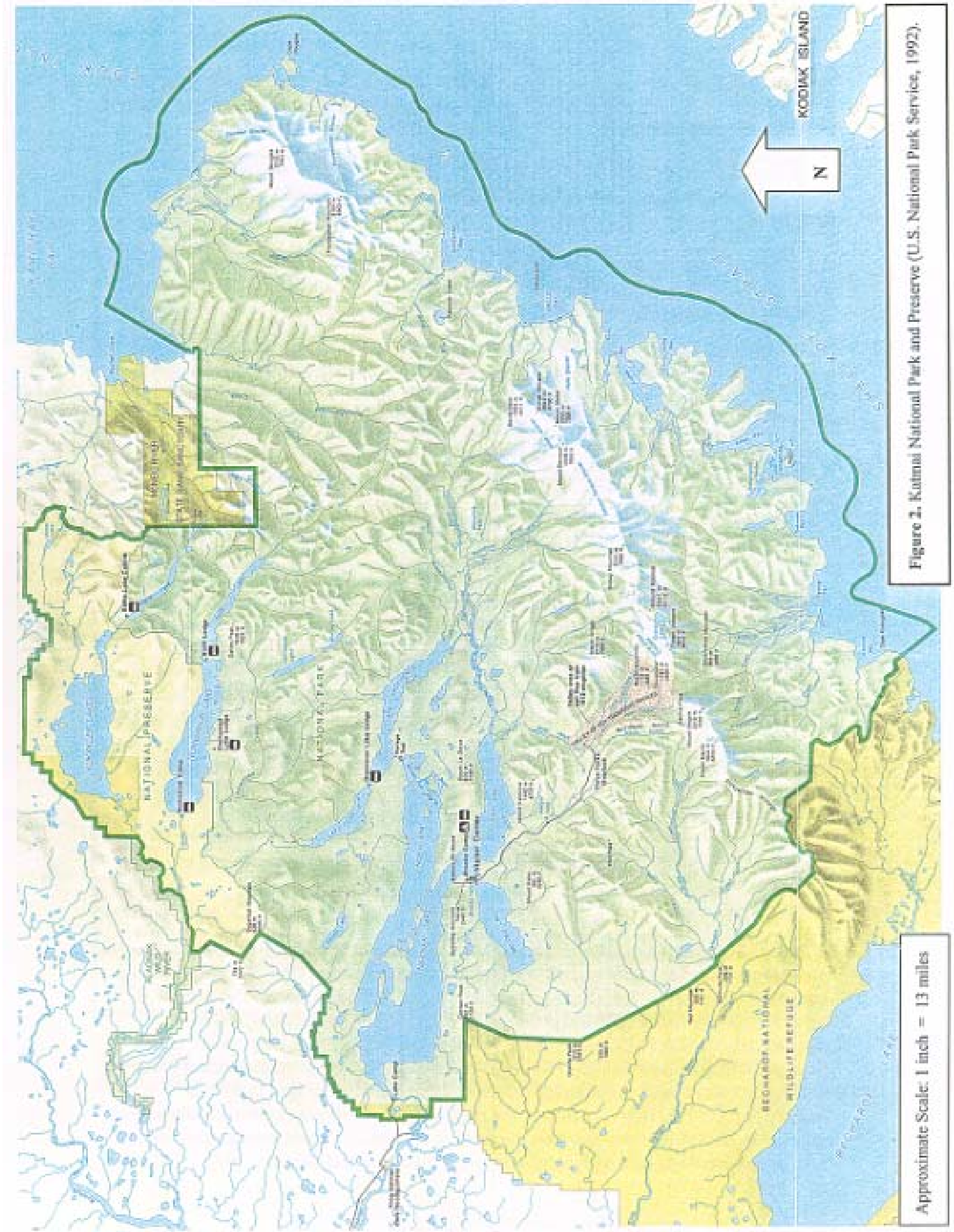


Figure 1. Regional Map, Katmai National Park and Preserve

In 1918, Katmai National Monument (1,088,000 acres) was established under authority of the 1906 Antiquities Act. Its primary purposes were to preserve the area for the study of volcanism and its scenic values. In 1931, the Monument boundaries were expanded to include areas along the Shelikof Strait coastline and the interior lake system (Brooks Lake, Lake Grosvenor, Lake Coville and part of Naknek Lake) to protect "features of historical and scientific interest, and for the protection of the brown bear, moose and other wildlife." Offshore islands within five miles of the coastline were added in 1942 to protect sea mammals and seabird nesting sites and to reduce illegal trespass by poachers who used the islands to access the Monument. The remainder of Naknek Lake (west



Approximate Scale: 1 inch = 13 miles

Figure 2. Katmai National Park and Preserve (U.S. National Park Service, 1992).

end) was added in 1969 "for the protection of the ecological and other scientific values of this land and the existing Monument…" (U.S. National Park Service, 1994).

In 1978, KATM was expanded to its present size (Figure 2) under authority of the Antiquities Act to protect brown bear habitat and watersheds vital to red salmon spawning.

The Alaska National Interest Lands Conservation Act (ANILCA) became law in 1980 (P.L. 96-487). With the passage of ANILCA, Congress redesignated the Monument as a National Park and Preserve. Section 202(2) of ANILCA states:

> "The monument addition and preserve shall be managed for the following purposes, among others: To protect habitats for, and populations of, fish and wildlife including, but not limited to, high concentrations of grown/grizzly bears and their denning areas; to maintain unimpaired the water habitat for significant salmon populations; and to protect scenic, geological, cultural and recreational features."

Section 603 of ANILCA designates the Alagnak River as a "Wild and Scenic River" and states:

> "Those segments or portions of the main stem [Alagnak River] and Nonvianuk tributary lying outside and westward of the Katmai National Park/Preserve…to be administered by the Secretary of the Interior."

The Wild and Scenic River Act (16 USC 1271-1287) was approved in 1968 and establishes a National Wild and Scenic Rivers System and prescribes the methods and standards through which additional rivers may be identified and added to the system. Rivers are classified as wild, scenic, or recreational, and hunting and fishing are permitted in components of the system under applicable federal and state laws.

As a unit of the National Park system, NPS management at KATM is committed to conserving the scenery and natural resources for the enjoyment of future generations (1916 NPS Organic Act, USC 1).

DESCRIPTION OF NATURAL RESOURCES

Climate

A maritime climate predominates at KATM with diurnal and seasonal temperature ranges normally confined to rather narrow limits (Young and Racine, 1978). Precipitation and air temperature vary in KATM depending on the geographic location. The climate is typically warmer and wetter along KATM's coast. At King Salmon, which is representative of KATM's inland climate conditions, the mean air temperature ranges from 14.9º F in January to 54.7º F in July. At Kodiak, which represents coastal climate conditions along the Shelikof Strait, the mean air temperature ranges from 29.9º F in January to 55.2º F in July. Obviously the park's higher elevations (Aleutian Mountains) experience much lower temperatures, depending on altitude. Most precipitation (60%) falls as rain from May through September (U.S. National Park Service, 1994). The mean annual precipitation for King Salmon is 19.8 inches, increasing to 67.5 inches at Kodiak (Figure 3) (National Oceanic and Atmospheric Administration, 1998).

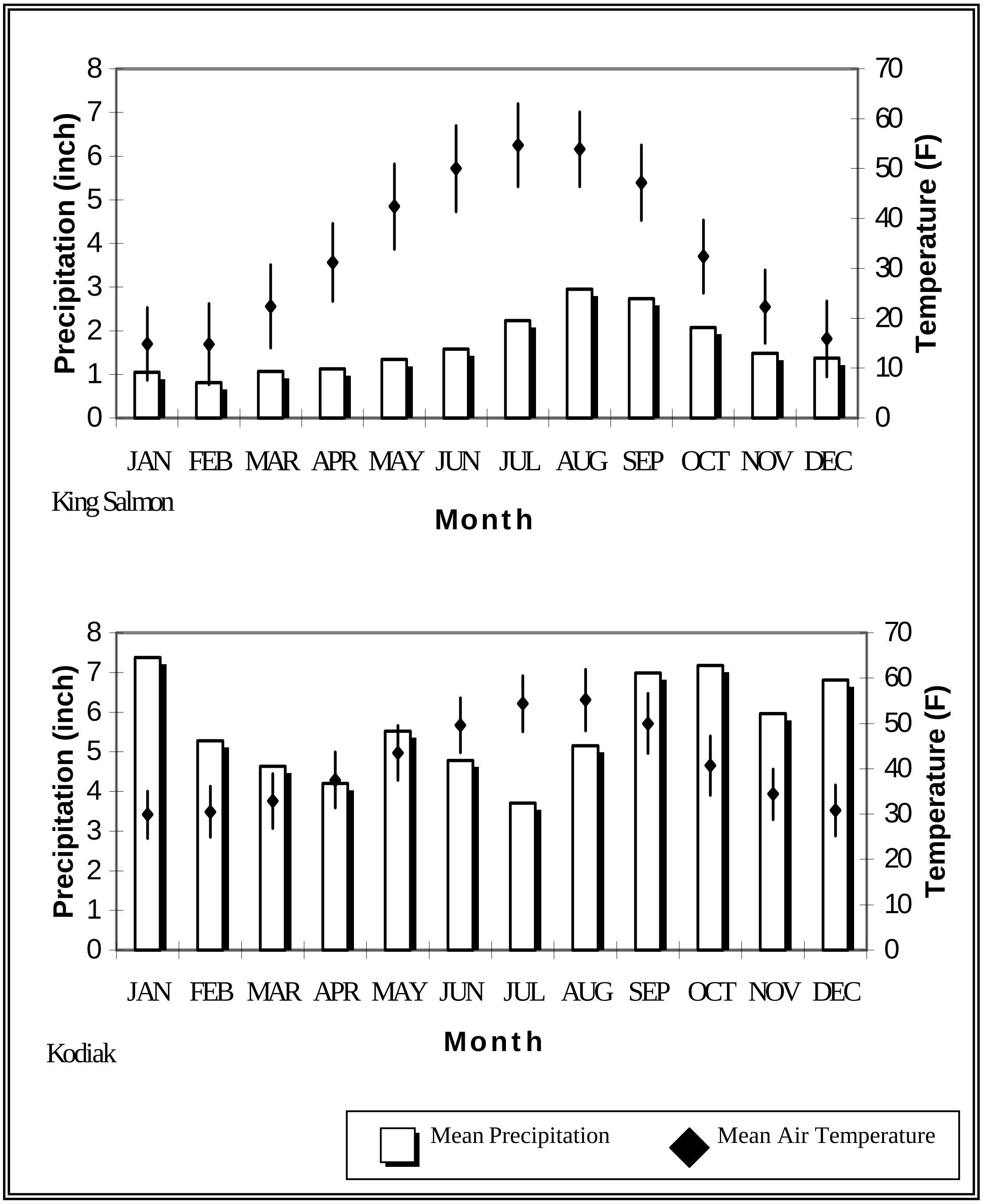


Figure 3. Monthly Mean Precipitation and Air Temperature Range (1961-1990), King Salmon and Kodiak, Alaska (National Oceanic and Atmospheric Administration, 1998).

Physiography

KATM contains four distinct physiographic regions: the Aleutian Range, the coast, the lake country, and the Bristol Bay lowlands (U.S. National Park Service, 1994). Glaciation has influenced the topography of each region; carving u-shaped valleys and deep lake basins, and depositing eroded materials transported by the ice advances.

The Aleutian Range is a volcanic mountain chain that rises more than 7,000 feet from fjord-like bays of the Shelikof Strait. The Aleutian Mountains parallel the northeasterly trend of the Alaska Peninsula across the entire area and separate the Shelikof Strait coast from the lake country surrounding Naknek, Nonvianuk, and Kukaklek lakes (Keller and Reiser, 1959). The lake country is comprised of low, rolling hills and large deep depressions, such as Naknek, Coville, Kulik, Nonvianuk and Grosvenor lakes. Many of the rivers drain from the highland areas to these lakes and flow into the Naknek or Alagnak rivers before emptying into moist tundra of the Bristol Bay lowlands. KATM's lowlands are described by Young and Racine (1978) as a transition zone where the interior Alaska white spruce (*Picea glauca*) forest gives way to tundra. This low-latitude forest-tundra ecotone occurs along much of the western coast of Alaska. Although located at a lower latitude, the tundra at KATM is similar to that found in arctic Alaska and attributed to the maritime climatic influences.

Geology

The Aleutian Range in KATM is a segment of the circum-pacific *Ring of Fire*, one of the most active volcanic belts in the world. Quaternary volcanism in the Aleutians is the result of plate convergence, approximately 7.0 cm/year, between the American and Pacific plates (Figure 4) (Kienle and Swanson, 1983). The relationship between tectonic movement (plate convergence) and volcanic activity was hypothesized in the 1920s. Fenner (1925) concluded an apparent coincidence of tectonic shocks (earthquakes) during the 1912 Novarupta volcanic eruption in KATM.

The structural geology of the Katmai region trends generally northeast-southwest along the Aleutian Range and lies on a slight homocline (strata having the same dip) dipping to the southeast. A dominant structural feature in the region, the Bruin Bay Fault, bisects KATM (Figure 5). To the north on the northwest side of this fault, lower to middle Jurassic intrusives and Tertiary extrusives are upthrown into surface contact with relatively flat-lying Upper Jurassic Naknek sandstone on the southeast side. Farther to the southeast, the sandstone is overlain and to some extent surrounded by Tertiary to Quaternary volcanics (Ward and Matumoto, 1967). Except for early thrust movement on the Bruin Bay Fault, the Alaska Peninsula was primarily a depositional feature until the Pliocene. Essentially all major tectonic features in the region were formed during the Pliocene, although regional uplift still persists (Burke, 1965). In detail, the geology and associated structure are very complex with igneous, metamorphic and sedimentary lithologies interacting at various scales.

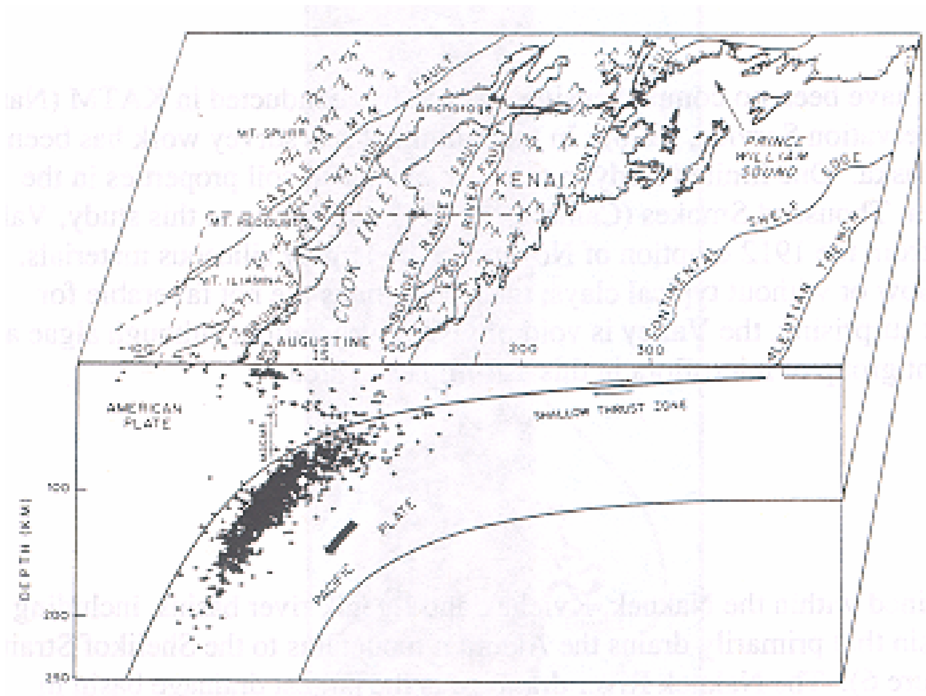


Figure 4. Subduction zone of Pacific Plate along the coast of Katmai National Park and Preserve illustrating locations "+" of individual earthquake hypocenters or initial rupture points (Stone, 1983).

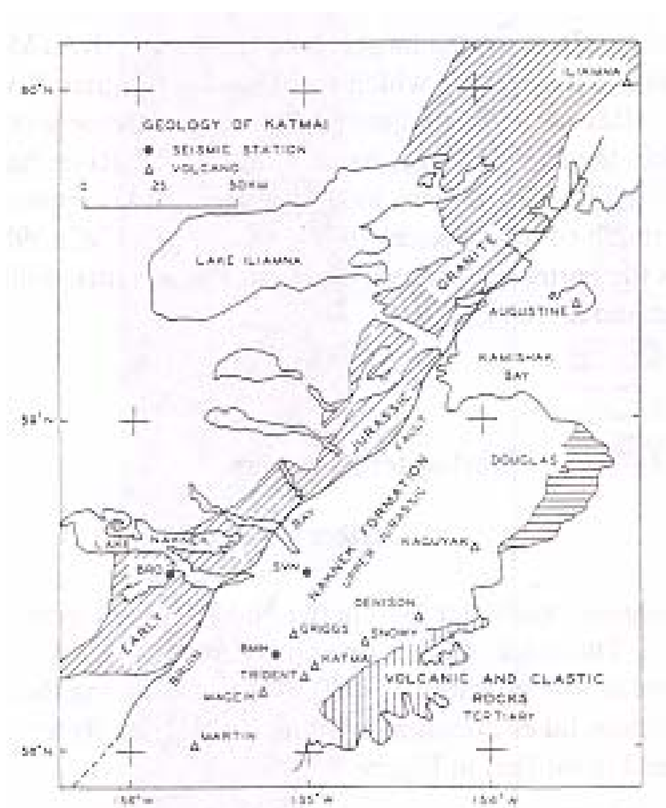


Figure 5. Location of Bruin Bay Fault in Katmai National Park and Preserve (Berg, et al., 1967).

Soils

Currently, there have been no comprehensive soil surveys conducted in KATM (Natural Resources Conservation Service, 1998). In fact, minimal soil survey work has been conducted in Alaska. One limited study in the park evaluated soil properties in the Valley of the Ten Thousand Smokes (Cameron, 1970). According to this study, Valley soils produced from the 1912 eruption of Novarupta are largely siliceous materials. These soils are low or without typical clays; thus, conditions are not favorable for organisms. Not surprising, the Valley is void of visible vegetation, although algae are still an important group of microflora in this ash-impacted area.

Hydrology

Watersheds

KATM is contained within the Naknek, Kvichak and Egegik river basins, including a coastal river basin that primarily drains the Aleutian mountains to the Shelikof Strait and Cook Inlet (Figure 6). The Naknek River drainage is the largest drainage basin in KATM. Seventy-three percent (2,660 mi^2) of the 3,640 mi^2 drainage is located within KATM's boundary (U.S. National Park Service, 1994). The Kvichak River basin is 60 miles wide and extends 170 miles northeastward from the northeast tip of Bristol Bay to the northwest slopes of the Aleutian Range (U.S. Department of the Interior, 1952). This basin contains two large lakes located outside of the park's boundary: Lake Clark (143 mi^2) and Lake Iliamna (1,226 mi^2), the largest lake in Alaska. KATM occupies only a small portion of this larger watershed, which includes the Alagnak River. Although not mentioned in KATM's Resources Management Plan, the extreme southwest corner of the park is contained within the Egegik River basin. The Egegik River basin extends from within 5 miles of the Shelikof Strait coast to Bristol Bay, and is approximately 40 miles in length (U.S. Department of the Interior, 1952). Along KATM's 398-mile coastline, the park encompasses the entire watersheds of its coastal streams, with the exceptions of Little Kamishak River and Strike Creek.

Surface Water

Freshwater Environments

Lakes

KATM contains the largest freshwater lake in the National Park system and some of the largest lakes in Alaska. These lakes make up approximately 8% of the park's surface area and most are found at low elevations (< 1000 feet msl) along the northern slope of the Aleutian Range. Major lakes contained within the Naknek River drainage are presented in Table 1 and identified in Figure 7.

Figure 6.
Katmai National Park and Preserve and Regional Watershed Boundaries
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Table 1. Major Lakes Contained within the Naknek River Drainage of Katmai National Park and Preserve (U.S. National Park Service, 1994).

Lake Name	**Area** (mi^2)	**Lake Name**	**Area** (mi^2)
Naknek	228.0	Idavain	4.2
Brooks	29.1	Hammersly	3.4
Grosvenor	28.5	Jo-Jo	2.6
Coville	13.3	Murray	1.0

The Alagnak River is a “Wild River” component of the National Wild and Scenic Rivers system and a unit area of the NPS administered by KATM. The Alagnak River is a tributary of the Kvichak River basin. Major lakes contained in the Alagnak drainage are presented in Table 2 and identified in Figure 7.

Table 2. Major Lakes Contained within the Alagnak River Drainage of Katmai National Park and Preserve (U.S. National Park Service, 1994).

Lake Name	**Area** (mi^2)	**Lake Name**	**Area** (mi^2)
Kukaklek	67.5	Pirate	0.8
Nonvianuk	51.5	Spectacle	0.8
Kulik	10.7	Mirror	0.6
Battle	5.0	Iron Springs	0.3

Igneous rocks intrude older sedimentary formations in the park, creating lake basins of heterogeneous parent materials (Gunther, 1992). The lake basins in the region were deeply carved by glaciers during several advances between 8,000 and 25,000 years ago. The deepest recorded lake depth is 530 feet in the Iliuk Arm of Naknek Lake. Lakes become much shallower toward the west as a result of glacial deposition (U.S. National Park Service, 1994).

KATM lakes at lower elevations typically freeze in early December and they usually become ice-free in early May. During the warmer summer months, thermal stratification seldom develops due to winds, which actively mix these lakes (Buck et al., 1978).

There are fewer lakes located along the Shelikof Strait coast. These coastal lakes are much smaller than those found in the park north of the Aleutian Range. Heard et al. (1969) believes that most lakes along KATM’s coast are glacial in origin and are relatively deep for their size. Dakavak Lake is the largest coastal lake, approximately 2.8 miles long and 0.6 miles wide (1.7 mi^2) with a depth greater than 69 feet.

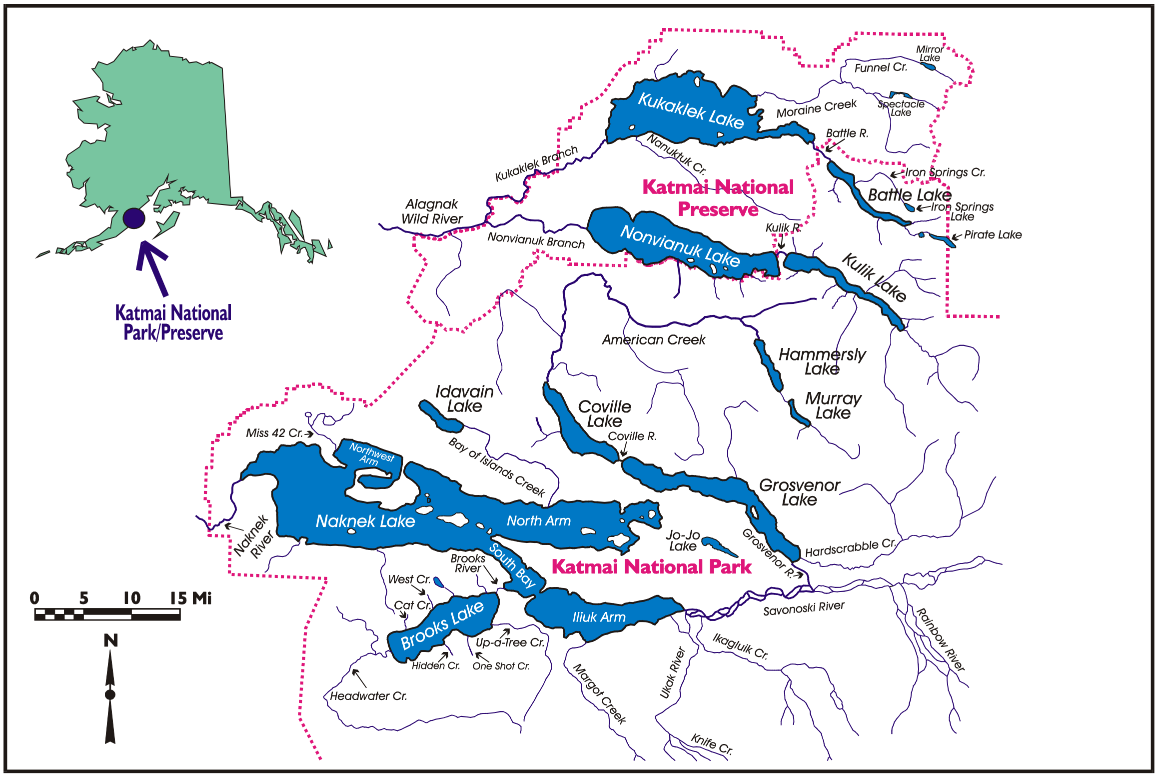


Figure 7. Location of Select Streams and Lakes in Katmai National Park and Preserve (Kavanagh, 1999).

Streams

The largest streams contained in the Naknek River drainage are Naknek, Coville, Grosvenor, Savonoski, Rainbow, Ukak, and Brooks rivers and American, Hardscrabble, Ikagluik, Margot, Idavain, and Headwaters creeks. The largest streams located in the Kvichak River drainage (Alagnak drainage) are Alagnak, Nonvianuk, Kulik and Battle rivers and Nanuktuk, Moraine, and Funnel creeks. The four KATM streams contained within the Egegik River basin are Contact Creek, Angie Creek, Takayato Creek, and the Kejulik River.

Along KATM's coast, the Kamishak River, Little Kamishak River, Strike Creek, and Douglas River flow into Kamishak Bay located in Cook Inlet. Numerous named (e.g., Katmai River, Alagogshak Creek) and unnamed streams flow down the characteristically short, steep drainage along the Shelikof Strait coastline (U.S. National Park Service, 1994).

There are no continuous stream flow data in KATM. The closest USGS stream gaging stations are located outside the park at Eskimo Creek (Naknek River basin - King Salmon, AK) and Kvichak River (Kvichak River basin - Igiugig, AK). Between 1990 and 1992, discharge was recorded on 19 streams in the park. The reported discharges ranged from 2 ft^3/sec in a tributary that feeds Brooks Lake to 530 ft^3/sec in American Creek (LaPerriere, 1996).

Wetlands

KATM contains extensive wetlands that include marine, estuarine, riverine, palustrine, and lacustrine environments (estimates exceed 1 million acres). For the Cowardin classification system, a wetland must have one or more of the following three attributes: (1) at least periodically, the land supports predominately hydrophytes; (2) the substrate is predominantly undrained hydric soil; and (3) the substrate is non-soil and is saturated with water or covered by shallow water at some time during the growing season of each year (Cowardin et al., 1979). The park's wetlands represent transitional environments, located between uplands and deepwater areas. Flora within these wetland systems exhibits extreme spatial variability, triggered by very slight changes in elevation. Temporal variability is also great because the surface water depth is highly influenced by changes in precipitation, evaporation and/or infiltration.

There are a number of tundra ponds, beaver ponds, and small tundra lakes along the park's western boundary. These bodies of water are shallow, frequently contain submerged and emergent aquatic vegetation, and occasionally have no surface connections with major stream systems (Heard et al., 1969). The Savonoski River/Bay of Islands area and the Margot Creek drainage, also located in the park's interior, contain extensive marshes and ponds. Along the park's coast, marine and estuarine wetlands (primarily under State jurisdiction) are common along with riverine, palustrine, and lacustrine wetland systems (U.S. National Park Service, 1994).

Glaciers, Lake Ice, and Snowpack

The Katmai region has a history of multiple glaciations by a piedmont glacier system, which at its maximum, extended nearly 100 miles west of the Aleutian Range across Kvichak Bay (Muller and Ward, 1966). Currently, glaciers make up 216,000 acres (6%) of KATM (U.S. National Park Service, 1994). The hydrologic cycle in the park is influenced in part by extensive glaciers and snowfields that supply vast quantities of silty meltwater to the headwaters of drainage basins during the summer months.

Mean annual frozen precipitation totals for King Salmon, which represent KATM's interior, and Kodiak, which represent KATM's coast, vary from 46.1 to 77.4 inches, respectively (National Oceanic and Atmospheric Administration, 1998). Seasonal ice and snow cover affects the characteristics of aquatic ecosystems. It controls the amount of light reaching the unfrozen water beneath the ice (Prowse and Stephenson, 1986). Ice can also prevent gas exchange between underlying waters and the atmosphere and may commonly lead to depletion of dissolved oxygen and the build up of reduced gasses such as CO_2, CH_4 and H_2S (Rouse et al., 1997). The processes accompanying ice formation during freeze-up and break-up have a wide range of effects on the bed, banks, and biota of lakes and rivers. These include frazil ice (aggregate of ice crystals formed in supercooled turbulent water) impact on fish and invertebrates, anchor ice growth, elevated water levels, channel blockage and increased scouring (Prowse, 1994.)

KATM is also underlain by discontinuous or isolated masses of permafrost, which can greatly influence the hydrologic cycle (Dearborn, 1979). For example, permafrost can prevent precipitation from recharging aquifer systems, thus surface runoff provides a greater contribution to lake and stream recharge.

Coastal Environments

KATM's boundary includes nearly 400 miles of rugged coastline of the Shelikof Strait and Cook Inlet on the Gulf of Alaska. Islands located within five miles of the coast are also administered by the park. These coastal drainages are characteristically short, with steep gradients. One exception is the Katmai River, which was impacted by volcanic ash deposited from the 1912 eruption of Novarupta. The heavy silt loads from the ash-laden watershed transformed this single channel system into a three-mile-wide braided river. The streams that empty into the numerous bays along the Shelikof Strait coastline range between 2.9 and 19.3 miles in length.

The U.S. National Park Service (1994) has identified 11 coastline classifications for KATM: 1) exposed rocky headland, 2) sheltered rocky shore, 3) wave-cut platform, 4) gravel beach, 5) mixed sand and gravel beach, 6) coarse-grained sand beach, 7) fine/medium-grained sand beach, 8) exposed tidal flat, 9) exposed tidal flat / moderate biomass, 10) sheltered tidal flat, and 11) marsh. Associated with these different coastal environments is a variety of aquatic biota (i.e., anthropods, molluscs, echinoderms, fish, etc.) that support both aquatic communities and terrestrial species along KATM's coast, including one of the park's biggest visitor attractions, the brown bear (*Ursus arctos*).

Volcanic Environments

A compilation of observations of volcanic eruptions since 1870 and ash stratigraphy shows that KATM has had a long history of volcanic activity (Ward and Matumoto, 1967). In 1912, Novarupta violently erupted. The 60-hour eruptive sequence yielded about 35 km^3 of tephra (pyroclastic material ejected during a volcanic eruption), the most voluminous outburst of the twentieth century (Hildreth, 1987).

In addition to Novarupta, five other volcanoes in the vicinity of Novarupta have been intermittently active since 1912: Mount Katmai, Mount Martin, Mount Mageik, Trident Volcano and Mount Griggs. Six more volcanoes, which have had no activity recorded in the last 200 years, are considered active: Mount Dension, Mount Stellar, Kukak Volcano, Kaguyak Volcano, Four-Peaked Mountain, and Mount Douglas (U.S. National Park Service, 1994).

Two crater lakes occur in the park: Katmai Crater Lake, which formed as a result of the 1912 eruption of Novarupta, and Kaguyak Crater Lake, which formed in recent prehistoric times. Neither lake has an outlet stream (U.S. National Park Service, 1994).

Volcanic activity has a significant impact on water chemistry and stream morphology. For example, in KATM, streams that were in contact with the 1912 tephra deposits had a different water chemistry than streams located outside the influence of volcanic activity (see **Water Quality** section) (Keith et al., 1990). Extensive physical changes in riparian and aquatic habitats have also resulted from volcanic-induced disturbances in the Cook Inlet region. Along with ash deposition, eruptions in the region have caused massive inputs of water and sediment to enter the stream channels emanating from glaciers and snowfields on the volcanoes (Dorava and Milner, 1999).

Some impacts from volcanic eruptions are short-term (< 5 years), while others last much longer. There are data to suggest significant fertilization of watersheds by ashfall in the region. Griggs (1920) reported that the ash from the 1912 eruption included 0.36% phosphorus, 0.47% magnesium and 3.8 % calcium. Although vegetation was greatly reduced during the first two years following the eruption, Griggs (1920) found plant growth to accelerate above normal after the second year. A similar correlation was observed in examining the growth history (1855 – 1951) of five spruce trees (*Picea spp*.) around Brooks Lake. As shown in Figure 8, an abrupt and rapid increase in annual growth rates occurred in 1914, peaking in 1918 (Eicher and Rounsefell, 1957). In comparing macroinvertebrate community composition in the Drift River (approximately 100 miles northeast of KATM), which was impacted by the 1989-1990 Redoubt volcanic eruption, with nearby undisturbed streams, Dorava and Milner (1999) found the Drift River macroinvertebrate communities still recovering after five years.

<u>Ground Water</u>

A petroleum contamination assessment at Brooks Camp identified a shallow (3 - 15 feet below ground surface) water table aquifer and a deeper artesian aquifer in the underlying igneous bedrock (U.S. National Park Service, 1997). Outside of a few independent site characterizations such as this, there is minimal information available on KATM's ground water resources, but some basic hydrogeologic principles can be inferred from the park's geology and geomorphic features.

Glacial deposits typically present favorable conditions for ground water. Streams that issue from the edge of glaciers pick up large loads of unconsolidated sediments, dumping the coarser materials some distance downstream. These outwash gravels occur in the form of outwash fans and outwash terraces and constitute shallow but productive aquifer systems. Where moraines dammed up melt water, such as the western edge of Naknek Lake, fine-grained sediments can accumulate producing aquitards or confining beds (Mandel and Shiftan, 1981). Glacial-fluvial sand and gravel deposits that underlie King Salmon are the primary aquifer(s) in the area (Waythomas, 1994). Information on selected water wells in the King Salmon area is presented in Appendix A.

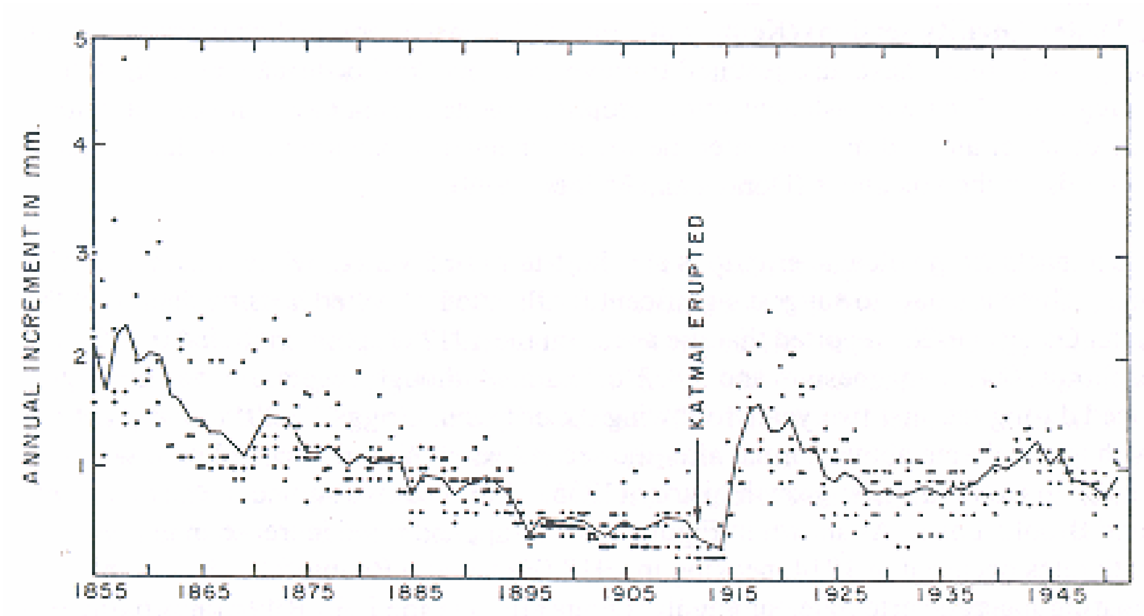


Figure 8. Annual growth increments of five spruce trees from Brooks Lake, 1855 – 1951, illustrating the marked long-term effect of ashfall on increased soil fertility (Eicher and Rounsefell, 1957).

Hydrologic properties in volcanic terrain vary greatly, making predictions about ground water uncertain. Some lava contain productive aquifers, while others are practically impermeable (i.e., good porosity caused by gas bubbles but poor permeability or interconnection of these pores). Loose pyroclastic rocks (pumice, ash, scoria) can be quite permeable when fresh, but the finer-grained varieties lose much of their permeability through compaction and weathering. Ground water quality can also be greatly influenced by volcanics. For example, noxious ions such as boron, arsenic and fluoride can be present at concentrations harmful for human consumption (Mandel and Shiftan, 1981).

KATM also contains coastal aquifers that are influenced by salt water, and aquifers contained in crystalline rocks (igneous units) that are influenced by faults and fractures. Based upon the variability in the park's hydrogeologic characteristics; ground water flow, depth, quantity, and quality can differ greatly over very short distances.

Fumaroles and Hot Springs

After the region was blanketed with pumiceous fallout from the 1912 Novarupta eruption, fumaroles (vents, usually volcanic, from which vapors and gases are emitted) discharged from the ash-flow sheet and were vigorously active when discovered in 1916

(Griggs, 1922). During his first visit to the Valley of Ten Thousand Smokes, Griggs (1917) wrote:

> "I can never forget my sensations at the sight which met my eyes as I surmounted the hillock and looked down the valley; for there, stretching as far as the eye could reach, till the valley turned behind a blue mountain in the distance, were hundreds - no, thousands - of little volcanoes…"

Dr. Shipley, who accompanied Griggs on the 1917 National Geographic Katmai expedition, reported a variety of odors (i.e., hydrogen sulfide and hydrochloric acid) coming from active vents in the Valley of Ten Thousand Smokes (Griggs, 1918). Fumarole temperatures up to 645º C were measured in 1919 (Allen and Zies, 1923). Cooling of the ash-flow sheet and the influx of surface waters caused the fumaroles to gradually cool and die out [Allen and Zies (1923), Fenner (1923), Zies (1924)]. No subsequent studies were done until 1979 after the fumaroles had become cold, except for a few in the near-vent region (Keith, 1984, 1991).

Hydrothermally active areas as hot as 90° C in 1986 have been mapped as discontinuous, elongate, clay-altered layers concentrated along some of the concentric fractures outlining the Novarupta caldera, as well as along systems of crossfractures (Keith, 1986). Keith et al., (1990) reported that thermal springs in the Valley of Ten Thousand Smokes, discharge about 20 meters below the surface of the ash-flow sheet through vertical cooling cracks in the tuff. In 1990, the maximum measured temperature of the springs was 29.8° C in early summer when waters in the upper valley were still frozen. Later in the summer, the temperatures decreased to approximately 17° C, most likely because of increased mixing with cooler surface melt-waters from the upper valley.

In the Valley of Ten Thousand Smokes, mineralogical evidence indicates three gradational stages of fumarolic activity that evolved as cooling took place: (1) high-temperature, vapor-phase degassing; (2) fumarolic gases reacting with water to form acids at the surface; (3) present-day residual near-neutral wet steam with temperatures as high as 90° C (Keith, 1991).

Water Quality

There have been several efforts since the 1970s to collect some baseline water chemistry for KATM's lakes and streams. Water samples have been collected in the Valley of Ten Thousand Smokes since 1979 to determine the extent to which the 1912 tephra deposits are still being leached by surface waters. Knife Creek and River Lethe, the two major streams draining the 1912 ash-flow sheet, are enriched in dissolved constituents (SiO_2, Ca, Na, K, Mg, Li, Cl, F, SO_4) compared to streams that have not had contact with the 1912 deposits (Keith et al., 1990).

Gunther (1992) conducted a chemical survey of remote lakes of the Naknek and Alagnak river drainages in KATM. Based on this survey, lakes within the Alagnak system exhibited lower surface water alkalinity than those of the Naknek system. This may reflect the influence of granitic parent materials in the Alagnak drainage. The Alagnak lakes exhibited higher concentrations of nitrate and lower concentrations of sodium than lakes of the Naknek drainage. According to Gunther (1992), the higher nitrate concentrations in the Alagnak drainage are probably due to lower productivity.

LaPerriere (1996) found the larger lakes in KATM to be oligotrophic or low in nutrients. LaPerriere (1997) classified these lakes as polymictic or able to circulate during the ice-free season due to frequent winds from coastal storms. The result is thermal instability that allows summer heat to mix deep into these lakes. This condition is illustrated in Figure 9, where the depth profiles of specific water quality parameters for Battle Lake show an almost straight-line profile. The mixing conditions and heat allow these lakes to be important producers of fish, particularly juvenile sockeye salmon.

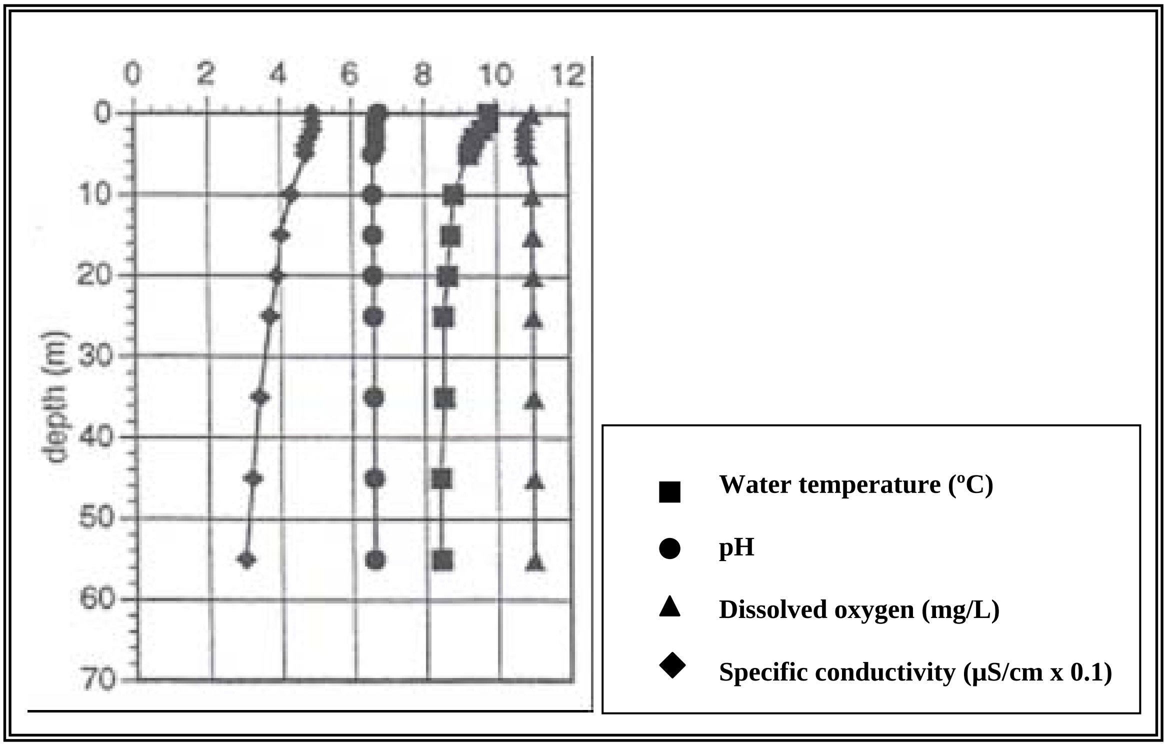


Figure 9. August 6, 1992 depth profiles of temperature, pH, dissolved oxygen and specific conductivity, Battle Lake (LaPerriere, 1996).

LaPerriere (1996) found the high-altitude lakes that were monitored to be acid sensitive. Of these, Battle Lake had the lowest alkalinity along with elevated concentrations of aluminum that possibly created toxic conditions. Gunther (1992) attributed the low alkalinity of Battle Lake in part to the inflow from an acidic tributary, Iron Springs Creek (pH = 4.1). The U.S. Fish and Wildlife Service (King Salmon, AK) conducted surveys in this acidic tributary and found virtually no traces of aquatic invertebrates or fish. Water quality surveys indicated that the source of this acidity is drainage from Iron Springs

Lake, a naturally acidic lake (pH = 3.6). Many of the naturally acidic lakes in the world can be found in volcanic regions. Not surprisingly, algal and zooplankton concentrations were low in Battle Lake.

High aluminum concentrations were found in Iron Springs Creek in the Alagnak drainage and Up-a-Tree, and Headwater creeks, which are located in the Naknek drainage. Aluminum concentrations that could be acutely toxic were measured in the Savonoski and Ukak rivers [(Gunther (1992), LaPerriere (1996)].

The Iliuk Arm of Naknek Lake receives turbid, glacial waters from the Savonoski and Ukak Rivers in KATM. As a result of increased turbidity, Iliuk Arm has Secchi disk readings of less than 1.6 to 3.3 feet (Heard et al., 1969). In contrast, transparency readings were recorded for Brooks Lake that ranged from 31.3 feet in July to 55.1 feet in August [Dahlberg (1972), Merrell (1964)]. Because of reduced light penetration in Naknek Lake, Goldman (1960) found less planktonic primary production per unit area than Brooks Lake.

Navigable Waters

In 1980, the State of Alaska established a navigability program to respond to federal land conveyances and land management activities under the Alaska Statehood Act, the Alaska Native Claims Settlement Act, and ANILCA. The basic purpose of the state's program is to protect the public rights associated with navigable waters, including the state's title to submerged lands. Because state, federal and native land units blanket the state, navigability questions have arisen for Alaskan rivers, lakes and streams. While the navigability of many of these waterbodies for conveyance purposes has already been established, navigability for title has not been determined for most waterbodies.

A major goal of the state's navigability program is to identify the proper criteria for determining title navigability in Alaska and to gather sufficient information about the uses and physical characteristics of individual water bodies so that accurate navigability determination can be made. The greatest hurdle to overcome in identifying and managing navigable waters in Alaska has been the differences of opinion between the state and federal government regarding the criteria for determining title navigability. The criteria for navigability takes into account geography, economy, customary modes of water-based transportation, and the particular physical characteristics of the waterbody. Final court decisions in Alaska are still needed to provide legal guidance for accurate navigability determination (Alaska Department of Natural Resources, 1999).

In a 1985 federal district court case, Alaska v. United States: No. 82-201, the Alagnak River, Nonvianuk River, Kukaklek Lake and Nonvianuk Lake were all found to be navigable waters (Alaska Department of Natural Resources, 1999).

KATM was created in 1918 and expanded several times prior to the Alaska statehood in 1959, and included several large lakes (e.g., Lake Brooks, Lake Coville, Lake Grosvenor, Iliak Arm, and much of Naknek Lake) and river systems. It is the position of the federal government that waters and submerged lands within the boundaries of NPS units created prior to Alaska statehood are federally owned (Gilbert, pers. comm., 1999).

Biological Resources

The biological resources at KATM are incredible. The park is home to the largest protected population of brown bears in North America and prime spawning habitat for salmon, which is the foundation of the Bristol Bay commercial fishing industry – the largest in the world. During 1972-91, the annual run of sockeye salmon bound for the Naknek and Kvichak drainages averaged 15.3 million fish, 53% of the total Bristol Bay run. From 1985-91, the sockeye escapement into the Naknek drainage averaged 1.8 million, and 5.4 million into the Kvichak drainage (U.S. National Park Service, 1994).

Diverse floral communities also exist in the park, in part because of the dynamic landscapes (i.e., glaciers, coast, lakes, rivers, etc.) and variation in topography, from sea level to 7600 ft. msl (U.S. National Park Service, 1994). Buck et al. (1978) prepared a comprehensive summary of natural resource information on the Naknek River drainage. This report includes an annotated bibliography and summary of the aquatic environments and biota, especially fisheries.

Water resources are especially important to the success of KATM's flora and fauna. The following two sections concentrate on the park's biological resources that are federally-listed as threatened or endangered and/or state-listed as endangered or species of special concern, to begin exposing some of the biological concerns that might serve as indicators to water-related issues.

Flora

The U.S. National Park Service (1994) grouped KATM's vegetation into five major categories:

> **Forest** (primarily occurs in lake country): Includes white spruce (and possibly black spruce), birch, and balsam poplar. Pure and mixed stands of varying levels of canopy cover exist.
> **Shrubland** (primarily occurs in the lake country and coast): Includes alder and willow, dwarf birch, and mixed sphagnum-shrub bog. Understory may contain a wide variety of low shrubs, herbs, grasses, ferns and mosses.
> **Moist Tundra** (primarily occurs in the Bristol Bay lowlands and lake country): Includes a continuous mat of mosses and lichens interspersed with low shrubs, herbs, grasses, and sedges.
> **Alpine Tundra** (occurs in Aleutian Range and lake country): Includes lichens, crowberry, and blueberry, and various herbs.
> **Herbaceous**: Includes tall grass meadow or grass meadow mixed with herbs or halophytic sedges. Found interspersed with other vegetation types and sometimes categorized with them.

There are no threatened or endangered species of plants listed by the U.S. Fish and Wildlife Service (1998b) in KATM. The following is a list of alien flora species reported in the park: shepherd's purse *(Capsella bursa-pastoris*) and pineapple weed (*Matricaria matricarioides*), occur at disturbed sites within the Brooks River developed area; clover (*Trifolium repens*) also occurs at the Brooks River development; specimens of bluegrass (*Poa pratensis*) and knotweed (*Polygonum aviculare*) have been collected in KATM's backcountry, away from significant visitor use areas (U.S. National Park Service, 1994).

<u>Fauna</u>

KATM contains a diverse assemblage of mammals, birds, and fish. The following information is based on a list of threatened or endangered species, as defined by the U.S. Fish and Wildlife Service (1998b) and endangered or species of special concern as defined by the Alaska Department of Fish and Game (1999).

Mammals

The Steller sea lion (*Eumetopias jubatus*) is a federally-listed threatened species that inhabits KATM's coastline. The Steller sea lion is listed by the state as a species of special concern. Steller sea lions have declined dramatically throughout the Gulf of Alaska and Bering Sea during recent decades (U.S. National Park Service, 1994). Sease and Loughlin (1999) documented a 53% decline of adult and juvenile (non-pup) Steller sea lions for the central Gulf of Alaska during June and July aerial surveys from 1990 to 1998. The central Gulf of Alaska includes the outer coast for KATM (Kavanagh, pers. comm., 1999).

There are also seven whales federally-listed as endangered species that occupy Alaska waters. These are the northern right whale (*Balaena glacialis*), bowhead whale (*Balaena mysticetus*), sei whale (*Balaenoptera borealis*), blue whale (*Balaenoptera musculus*), fin whale (*Balaenoptera physalus*), humpback whale (*Megaptera novaeangliae*) and sperm whale (*Physeter macrocephalus*). Although the park's coastal waters are too shallow for some of the deep-water species (i.e., northern right and blue), fin whales frequent areas adjacent to KATM's coast and there were sightings of humpback whales off of KATM's coast last year (Kavanagh, pers. comm., 1999). The humpback, northern right, and blue whales are also state-listed endangered species. The beluga whale (*Balaena mysticetus*), specifically the Cook Inlet population, is listed by the state as a species of special concern. Beluga whales have been observed in the Naknek River and along KATM's coast.

Birds

The Aleutian Canada goose (*Branta canadensis leucopareia*) is listed as a federally threatened species, and the American peregrin falcon (*Falco peregrinus anatum*) and short-tailed albatross (*Diomedea albartrus*) are listed as federally endangered species. The short-tailed albatross is a state-listed endangered species. Species of special concern listed by the state include the Aleutian Canada goose, American peregrine falcon, arctic peregrine falcon (*Falco peregrinus tundrius*), northern goshawk (*Accipiter gentilis laingi*), Steller's eider (*Polysticta stelleri*), and olive-sided flycatcher (*Contopus cooperi*). The Aleutian Canada goose and American peregrine falcon have not been documented but may occur seasonally in KATM (U.S. National Park Service, 1994). The Steller's eider, which occurs in southwestern and western Alaska is proposed for listing as a federally threatened species.

It should be noted that more than seven thousand sea bird carcasses were recovered from KATM's coast following the *Exxon Valdez* oil spill (U.S. National Park Service, 1994). A graphic example of a water resource impact extending to biological communities.

WATER RESOURCE ISSUES

The park's water-related issues presented in this section were identified during a 10-day information-gathering effort in KATM and Anchorage by the author, extending to numerous follow-up telephone calls after departing Alaska. Along with a technical literature review, information sources included review of a 1993 KATM issues-overview trip report prepared by the NPS Water Resources Division (U.S. National Park Service, 1993), and interviews with NPS management and other federal and state agencies.

Baseline Inventory and Monitoring

To effectively manage natural resources, inventory and monitoring activities should integrate into the overall natural resources planning and management process. Information obtained from these activities better assist the NPS toward understanding how the various environments in a park unit function naturally and help to isolate anthropogenic changes. The majority of scientific interests in KATM have centered around the 1912 Novarupta eruption. Griggs (1920, 1922) and Fenner (1920, 1922, 1923, 1925, 1926, 1950) accumulated significant information on volcanoes in the region. Curtis (1968) and Hildreth (1982) studied the tephra deposits from the 1912 eruption, and Keith (1984, 1986, 1991) studied hydrothermal activity in the Valley of Ten Thousand Smokes.

With its large landmass, low population, and limited resource development, relatively little is known about Alaska's water resources. The U.S. Geological Survey has calculated that Alaska in 1995 had an average of one stream gaging station per 8,395 square miles, compared to an average of one gage per 336 square miles in the lower 48 states (Bayha et al., 1997). This is particularly alarming because only 45% of the Alaska stream gage sites meet the U.S. Geological Survey's minimum 10-year record length, which is necessary to support a statistically reliable regional flow analysis (U.S. Department of the Interior, 1998).

During the summers from 1990-1992, a study was conducted to begin establishing water quality baseline information at KATM (LaPerriere, 1996). This water quality study assessed conditions in 11 large lakes and some of the important inlet, outlet, and connecting streams along the Naknek and Alagnak drainages within KATM (see **Water Quality** section for major findings). Data needs and long-term monitoring recommendations for KATM were presented by LaPerriere (1996) and included:

1. Bathymetrically map large lakes as needed to compliment future studies.
2. Establishing GPS-fixed stations in the deepest spot of major basins of each lake to be monitored. These sites will provide comprehensive (max. depth) water quality and biological profiles for each lake.
3. Take monthly Secchi disc readings during the ice-free season and calculate seasonal averages. Data will provide "early detection" of possible eutrophication and justification for intensive limnological studies.

4. Gage the largest streams in KATM in conjunction with the U.S. Geological Survey. Flow data are needed for any stream where water quality characteristics are being measured.
5. Monitor streams used for drinking water by staff and visitors for comparison to drinking water standards.

To follow-up with LaPerriere's study, KATM currently collects some basic water quality parameters (pH, turbidity, temperature, dissolved oxygen, Secchi depth readings, etc.) during the ice-free season for 11 lakes in the park (Hamon, pers. comm., 1999).

In 1996 and 1997, the U.S. Fish and Wildlife Service sampled six sites (three per year) for hydrocarbons in KATM waters that receive heavy public use (Kulik Lodge, Grosvenor Lake Lodge, Alagnak Wild River, Naknek Lake, Brooks Lake and Lake Camp). The elevated hydrocarbon concentrations and visual observations reported at several sites during this project justify the need for follow-up sampling and analyses (Johnson and Berg, 1999).

As a result of low alkalinity recorded in waters in the Alagnak drainage, Gunther (1992) stated that this drainage should be a high-priority for study if acidic deposition were to occur in the region. These studies would need to examine soil development and base-cation exchange capacity, the relative importance of surface and groundwater inflow in each drainage, and internal alkalinity generation in the lakes. It should be noted that the average pH recorded from 16 precipitation events in KATM (1985-1986) was 5.0, which is slightly acidic. Heavy metals were also found in the precipitation samples (U.S. National Park Service, 1994).

Basic biological knowledge of KATM's aquatic environments is also lacking. Buck et al. (1978) stated that research in the Naknek basin should focus on: 1) phytoplankton species distribution, abundance and diversity, and annual cycles of primary productivity; 2) zooplankton population dynamics; 3) invertebrate species distribution, abundance, and diversity, particularly aquatic insects; 4) salmon spawning areas, age structure, and juvenile use of habitats for coho (*O. kisutch*) and chinook (*O. tshawytscha*); and 5) population dynamics of rainbow trout (*O. mykiss*), lake trout (*Salvelinus namaycush*), Arctic grayling (*Thymallus arcticus*), dolly varden char (*S. malma*), and Artic char (*S. alpinus*).

The U.S. Environmental Protection Agency (EPA) has endorsed the use of biological integrity as an indicator of environmental condition and ecological health. It is unique among currently used indicators in that 1) it uses information collected directly from the aquatic organisms and their surrounding biological community, 2) the biota are shaped by all environmental factors to which they are exposed over time, whether chemical, physical, or biological, and 3) it combines multiple, community level, biological response characteristics into an indicator of cumulative environmental impacts (Karr 1991, 1993). The Alaska Department of Environmental Conservation has initiated two pilot bioassessment projects in southeastern Alaska, Admiralty Island and Prince of Wales

Island. The objective of these two projects is to evaluate U.S. EPA's Rapid Bioassessment Protocols for use in Alaska (Davis et al., 1996). The Rapid Bioassessment Protocols were designed as relatively inexpensive screening tools for determining if aquatic environments were supporting the unimpaired biological communities (Plafkin et al., 1989). Although these protocols were made for use in fluvial environments, EPA has initiated efforts to develop protocols for lake systems, which would be more applicable for KATM (U.S. Environmental Protection Agency, 1995).

Another example of baseline inventory and monitoring needs is found at Naknek Lake. Since the end of the Pleistocene, there has been a decline in the lake's water level, with a rapid drop within a few years after the 1912 Novarupta eruption. Possible causes for the change include: 1) a long-term change in the regional precipitation regime, 2) a change in the mass balance of the glaciers at the headwaters of the Naknek drainage, 3) downcutting of Naknek River through the terminal moraine that dams Naknek Lake, or 4) a seismically induced shift in the elevation of the Naknek River bed (U.S. National Park Service, 1994).

In 1990, an Aquatic Resources Inventory and Monitoring Workshop was held in Anchorage with resource managers from Alaskan parks. The following is a summary of suggestions presented during this meeting:

1. <u>Goal for Inventory and Monitoring</u>: to develop a meaningful database to assess the status and variation of representative aquatic resources in Alaskan parks.
2. <u>Inventory</u>: A synoptic survey of aquatic resources is required prior to implementing a monitoring program. Park units should be divided into sub-units based on common environments with surveys conducted for each sub-unit.
3. <u>Monitoring</u>: Project design should be based on regional objectives and specific park concerns, interests, and objectives. Quantitative sampling at several trophic levels is essential, unless there is a need to focus on a specific resource.
4. <u>Methods</u>: Standardization and documentation of methods is essential, especially for region-wide assessments of status and variation.

In response to the 1990 Aquatic Resources Inventory and Monitoring Workshop, Potts et al. (1993) prepared a proposal for long-term ecological monitoring for KATM. The objectives of this proposal were to establish KATM as one of the national Inventory and Monitoring prototype NPS units and to develop and implement a program of long-term ecological monitoring of the large lakes and large rivers in KATM. Unfortunately, this proposal was not funded at the national level (Deschu, pers. comm., 1999).

The NPS Water Resources Division is currently in the process of preparing a comprehensive summary of existing surface-water quality data for KATM, *Baseline Water Quality Inventory and Analysis, Katmai National Park and Preserve*. The information contained in this report will include data, with some data analysis, from several EPA national databases (i.e., STORET). The report is scheduled for completion in 1999 (Tucker, pers. comm., 1999).

Inventory and monitoring programs for natural resources in the park will assist both state and federal agencies with various management elements. This is especially important with subsistence management. Since 1990, the federal government has assumed responsibility for subsistence game management on federal lands. Federal subsistence fisheries management is scheduled to go into effect on October 1, 1999 unless the Alaska State Legislature passes a referendum to include a rural reference vote on the ballot. The two major issues that concern subsistence management at KATM are the conservation of renewable resources and the opportunity for rural residents to participate in traditional subsistence harvests. ANILCA identifies specific activities related to subsistence that require NPS participation. These include population monitoring studies, determination of rural residents, administration of cabin and access permits, administration of special harvest permits, limiting subsistence activities, if necessary, and review of park programs for compliance (U.S. National Park Service, 1994).

Climate Change and Influence on Water Resources

One of the more significant natural resource issues in Alaska is climate change (Nelson, pers. comm., 1998). Paleoclimatologists have used proxy data (i.e., ice cores, tree rings, etc.) to reconstruct the earth's historical climate. These data have resulted in remarkable discoveries, including the fact that climate has changed dramatically in the past and the global mean temperature has risen approximately 1 degree Fahrenheit on average the past 100 years [Trenberth (1997), Rouse et al. (1997)]. Northern hemisphere spring and summer snow cover, monitored by satellite imagery since 1973, has decreased by 10 % since 1987 (Trenberth, 1997). The environmental concerns associated with climate change have produced varied explanations from natural causes to human-induced impacts (i.e., burning fossil fuels, deforestation, etc.). Most of the scientific community believes the climate change we are currently experiencing is primarily human-induced.

The burning of fossil fuels alters the balance of radiation on Earth through both visible particulate pollution (called aerosols) and gases that change the composition of the atmosphere. The latter are referred to as "greenhouse gases" because they are relatively transparent to incoming solar radiation, while they absorb and reemit outgoing infrared radiation, thus creating a blanketing effect that results in warming.

KATM's environment is thought to be very susceptible to climate change. For example, Pinney and Begét (1991) reported that rapid environmental changes and glacial fluctuations on the Alaska Peninsula might be in response to transient changes in the concentration of atmospheric greenhouse gases and solar intensity. Climate also has a great influence on peatlands, which are found in KATM's lowlands and lakecountry (Belland and Vitt, 1995). Changes in moisture supply and thermal regime could alter topography and vegetation, which in turn could alter the water surfaces of northern peatlands and thus alter the natural delivery of CO_2 and CH_4 from surface waters to the atmosphere (Rouse et al., 1997). Increases in temperature can also extend ice-free seasons which will usually lead to increases in the ratio of evaporation + evapotranspiration to precipitation, resulting in less water found in the landscape (Schindler, 1997).

Because of the scarcity of real-time records, many regional climate summaries have relied heavily on modeled predictions, which are themselves of questionable validity (Schindler, 1997). Basic research and long-term monitoring are needed to compliment on-going regional and global efforts to better understand the causes and consequences of climate change. Research and monitoring needs presented by Rouse et al. (1997) include: 1) meteorological monitoring stations in remote areas, 2) accurate water balances for lakes and wetland systems, 3) better understanding of thermal behavior for wetland systems, and 4) better understanding the carbon budget of freshwater systems. According to a 1993 report by Potts et al., the U.S. National Weather Service has expressed a desire to assist KATM with the establishment of meteorological stations in the park. A proposal was also made by the Soil and Conservation Service in 1993 to assist the park in the establishment of one or more snow depth survey stations (U.S. National Park Service, 1994). Currently, two snow depth survey stations are established near the Brooks River area and Valley of Ten Thousand Smokes. These sites are monitored on a scheduled frequency with the data provided to the Soil and Conservation Service. KATM has recently prepared a funding request through the "NPS Fee Demo" program to install an automated weather station for the Brooks River area (Clark, pers. comm., 1999).

Nutrient Cycling

KATM's aquatic ecology is heavily dependent upon the annual influx of nutrients with the upstream return of millions of adult salmon. All five Pacific salmon (*Oncorhynchus*) are found in KATM. Spawning runs of fish produce nutrients to steams and lakes by excretion, release of gametes, and their own mortality (Allan, 1995). An example is found in a report by Richey et al. (1975) who identified a phosphate peak following the die-off of kokanee salmon (*O. nerka*) in a small tributary in Lake Tahoe, California. In Sashin Creek, Alaska, isotope analysis showed that nitrogen and carbon derived from a spawning run in Pacific salmon (*Oncorhynchus spp.*) were incorporated into periphyton, macroinvertebrates and fish (Kline et al., 1990). Both phosphorus and nitrogen have been shown to stimulate the primary production of aquatic systems.

Anadromous and Resident Fisheries

Based on archeological work in the Katmai region, early natives made extensive use of fish. The first change in the pattern of subsistence fishing took place in the 1890's, when the Arctic Packing Company established a sockeye salmon saltery at Naknek. During the early days of commercial fishing on Bristol Bay only sockeye salmon possessed value. Any fish believed to detract from the all important sockeye runs was considered worthy of eradication. During 1920-1925, the U.S. Bureau of Fisheries undertook annual "fish eradication" programs in the Naknek watershed. After a two-year lapse in the eradication program, it was revived in 1928 in the form of a bounty for each "predator" fish removed from the watershed and continued until 1941 (Montague, 1974). The Alaska Department of Fish and Game (ADF&G) and the NPS developed a Master Memorandum of Understanding (MOU) in 1982. The MOU recognizes that ADF&G and the Boards are mandated the authority and responsibility to manage, control and regulate subsistence, commercial and recreational uses of fish in KATM, in a manner consistent with ANILCA (State of Alaska, 1984). As discussed, federal susbsistence fisheries management may go into effect on October 1, 1999, if approved by the Alaska State Legislature.

KATM contains a substantial portion of sockeye salmon (*Oncorthynchus nerka*) spawning habitat upon which the Bristol Bay commercial salmon fishery, and thus the regional economy depend. The U.S. National Park Service (1994) reports the most significant factor affecting salmon populations in KATM is the commercial fishery. The Kodiak office of Commercial Fisheries monitors salmon populations spawning in drainages on the Shelikof Strait coast of Katmai. The Homer office of Commercial Fisheries monitors populations spawning in the Kamishak and Douglas drainages in Kamishak Bay. The King Salmon office of Commercial Fisheries currently monitors populations spawning in the Naknek and Alagnak drainages (U.S. National Park Service, 1994).

There are numerous and complex fishery issues that extend beyond the objectives of this report or a more comprehensive Water Resources Management Plan (WRMP). For example, there is escalating sport fishing pressure on the Alagnak River drainage with associated mortality and mutilation of rainbow trout, even though “catch-and-release” regulations are in effect (Kavanagh, pers. comm., 1999). In response to fishery issues such as this, KATM formally submitted a FY99 technical assistance request to the NPS Water Resources Division to assist the park in preparing a Fisheries Management Plan (FMP). KATM’s FMP will be a comprehensive plan that prioritizes the park’s information needs for fisheries to address high-priority fishery issues. This plan will integrate NPS and State policies and appropriate legislative mandates into park-specific management actions.

Recreational Management Issues

Park visitation has risen sharply in the last decade. Sightseers, anglers, and hunters routinely fly or boat into KATM to take advantage of the park’s pristine natural resources. With an increase in visitor use comes an increase in resource impacts. For example, the recreational demands by freshwater anglers in southwestern Alaska have more than doubled over the past decade. As angling pressure increases in KATM, boat operators venture further into headwater streams to avoid crowding. Today, jet-driven boats are becoming more popular because of their shallow draft. Shallow headwaters are preferred by Pacific salmon (*Oncorhynchus*) and rainbow trout (*Salmo gairdneri*) as sites of egg deposition for reproduction. Based on a 1992-1993 study by the University of Alaska at Fairbanks, jet boat operation can lead to significant salmonid embryo mortality through mechanical shock, intrusion of fine sediments into the gravel affecting eggs that remain in redds, and the removal of gravel covering eggs in redds with subsequent washing away of eggs (Horton, 1994).

In response to increased visitation, the NPS, beginning next year, will require cruise ships operating in Alaska's Glacier Bay to record smokestack emissions and measure underwater noise so the NPS can research cruise ship effects on Glacier Bay National Park and Preserve. KATM may warrant a similar assessment with increases in coastal visitation.

American Creek Streambed Disturbance

American Creek is the headwaters of the Naknek drainage in KATM. This creek is an important spawning stream for sockeye salmon. Prior to 1978, only the lower one-mile of American Creek was within the boundary of KATM. During this time, motorboats were prohibited within the monument except on Naknek Lake. The creek was incorporated into KATM's boundary in 1978 when the monument was expanded. At the same time when ANILCA redesignated the monument as a park and preserve in 1980, it opened the park unit to motorized access by float planes and motorboats. Now, most all recreational uses in American Creek are concentrated within the lower 6 miles of the river (Jope and Welp, 1987).

A study by NPS staff was carried out during the summers of 1986 and 1987 to evaluate resource condition under the current permit system. The most serious consequence of human activity along American Creek identified during the study was the increased rate of erosion and alteration of streambed morphology that results from jet boat use. Permanent photo points were established in 1989 to monitor riparian vegetation cover and erosion along the creek every 2 to 4 years (U.S. National Park Service, 1994).

Alagnak Wild River Bank Erosion by Boat Traffic

The Alagnak River was designated as a Wild River in 1980 under ANILCA and the National Wild and Scenic Rivers Act. The NPS and the State of Alaska co-manage the upper 56 miles of this navigable river. In 1983, a management plan was developed that presents the management objectives and the issues pertinent to the Alagnak. Visitation on the river is monitored at only one location, the Nonvianuk Lake outlet. No other activities have been initiated by KATM to monitor use levels, user impacts, or resolve visitor conflicts (U.S. National Park Service, 1994). Since 1983, recreational use on the river has increased, and so have the water resource impacts. Although the river's riparian areas are generally undeveloped and heavily vegetated, the banks are actively eroding in several areas as a result of boat wake impacts. In 1998, the U.S. Geological Survey initiated an erosion monitoring effort on the Alagnak (Dorava, 1998a). After monitoring 14 sites from July to September 1998, bank erosion measurements ranged from 0 to > 28 inches, where erosion exceeded the length of the erosion pin (Dorava, 1998b). Along with the 1998 erosion data collected by the U.S. Geological Survey, a plan will be prepared for subsequent erosion monitoring along the river. This erosion monitoring effort by the U.S. Geological Survey is part of a 3-year NPS/USGS water quality and monitoring partnership program, "Human Impacts on Water Quality and Riparian Habitats along the Alagnak Wild and Scenic River, Katmai National Park and Preserve", that will also include collection of the following information: human use data, fishery data, and water quality data.

There is also an interest in constructing a road that might cross the Alagnak Wild River to access Cominco Mine, located north of Iliamna Lake (U.S. National Park Service, 1994). In response to this and other anticipated natural resource impacts, KATM prepared a project statement, “Develop Action Plan for the Alagnak Wild River (KATM-N-012)” to implement informed decision-making for the wild river corridor. This project was recently funded through the NPS Natural Resources Preservation Program (NRPP). A 3-year comprehensive river corridor plan is expected to be finalized in 2002 (Clark, pers. comm., 1999).

Water Resource Impacts from Backcountry Facilities

Seven backcountry lodges exist within KATM, and at least four more are being developed or planned on private inholdings, including the Alagnak Wild River, Naknek River and along the coast (Johnson and Berg, 1999). Although there is considerable information on a few popular facilities (i.e., Brooks Camp, Lake Camp), water resource impacts from most backcountry facilities and sites (i.e., concentrated camping areas) are not well documented. The U.S. National Park Service (1994) identified several on-going activities that could affect natural resources in KATM’s backcountry, including:

1. Landing and beaching of floatplanes on lake shores and river banks;
2. Landing of wheeled planes on beaches and gravel bars;
3. Beaching of boats and rafts along river banks;
4. Concentrated camping sites associated with water access (i.e., along river or lake banks);
5. Use of all-terrain vehicles (ATVs) and four-wheel drive vehicles within KATM boundaries.

This list focuses on physical impacts, but there are several examples of chemical impacts that could influence KATM’s water resources.

KATM’s staff conducted a Level 1 hazardous waste survey at the Grosvenor concessions area (Grosvenor Lake Lodge) in 1993. The lodge is located on the northeast side of a narrow neck of land that separates Lake Coville and Grosvenor Lake. At this particular facility there is a lodge, three cabins, bathhouse, kitchen, dining area, employee facilities, generator shed and maintenance shed. During the survey, areas adjacent to the generator shed were void of vegetation. The floor of the generator shed appeared to be contaminated from petroleum spills (McClenahan, 1993). In 1996, a hydrocarbon sampling effort at the lodge by the U.S. Fish and Wildlife Service revealed low levels of polycyclic aromatic hydrocarbons (PAHs), but visual observations of an oil sheen suggested a history of hydrocarbon contamination that might warrant further investigation (Johnson and Berg, 1999).

In 1996, the NPS contracted with the U.S. Fish and Wildlife Service to collect water and sediment samples at Kulik River Lodge for hydrocarbon analyses. According to the laboratory results, total PAH’s did not indicate significant contamination at the site, but a hydrocarbon release in the past is a possibility (Johnson and Berg, 1999).

The United States Air Force established two recreation areas immediately east of King Salmon in the 1950's. One site is located approximately 4 miles southeast of King Salmon and approximately 3.5 miles west of KATM's boundary on the Naknek River and the other site is 6 miles east of King Salmon inside the park's boundary, along the banks of Naknek Lake. The Naknek River and Naknek Lake sites were used by the Air Force between 1956 – 1977 and 1956 – 1979, respectively. Along with these two sites being used as recreational areas, they were also used by the Air Force as landfills for hazardous materials. Waste oils, fuels, and polychlorinated biphenyl's (PCBs) were among the wastes disposed at these sites. A 1989 report prepared by the Hazardous Material Technical Center for Elemdorf Air Force Base concluded that a potential exists at both sites for contamination of surface water, soils, and/or groundwater. The Naknek River was listed by the Alaska Department of Environmental Conservation (1996b) as a high-priority water quality limited waterbody, which require water quality assessments to define the extent of pollution and what remedial efforts need to be employed. The pollutant sources were identified as "landfill" and "fuel storage". In 1997, sediment and water samples collected at the Naknek Lake site contained elevated concentrations of hydrocarbons (Johnson and Berg, 1999).

Coastal Issues

The State of Alaska Department of Natural Resources (DNR) manages the tidelands adjacent to KATM's coast. Several years ago, the DNR received applications for the placement of mooring buoys adjacent to KATM to accommodate commercial operators who are engaged in conducting bear viewing and fishing trips. The NPS objected to the issuance of such mooring buoy permits adjacent to the designated wilderness, especially in ecologically sensitive bays such as Amalik/Geographic Harbor, Kaflia Bay, and Kukak Bay, until such time as a joint management agreement or plan could be drafted. The State expressed interest in working with the NPS and the NPS worked jointly to assemble baseline information about resources and uses along the coast. Public input was also solicited. The DNR has identified the coastal area adjacent to KATM as a potential "Special Use Area" to be designated in recognition of the complexities of rich coastal and upland resource, the rapidly increasing public and commercial uses of the area, and the conflicting demands for public use. At this time no final decision has been made regarding this designation (Alderson, pers. comm., 1999).

KATM's 398 miles of marine coastline are at constant risk from environmental threats associated with petroleum development, storage, and/or transportation. The Valdez terminal in Prince William Sound receives approximately 24 billion gallons of oil per year via the TransAlaska Pipeline. There are also 15 production platforms operating in Cook Inlet. The Drift River Marine Terminal is a privately owned offshore oil loading platform in Cook Inlet with an onshore storage facility. The Nikiski oil terminal and refinery is located on the eastern shore of Cook Inlet. These two oil-loading facilities transfer over 3.3 billion gallons of oil per year (Potts et al., 1993).

The strong currents and a high tidal range along the Alaskan coast can transport spills great distances from their source. For example, a 1970 oil spill extended from the

KATM coast to the Montague Islands, over 200 miles away. A report prepared by the U.S. Department of the Interior (1970) concluded that this spill was caused by deliberate discharges of slop oil and/or ballast from tankers.

<u>*Exxon Valdez* 1989 Oil Spill</u>

On March 24, 1989, the tanker vessel *Exxon Valdez* grounded in Prince William Sound, rupturing cargo tanks and spilling approximately 11 million gallons of crude oil into the sea. This accident resulted in the most extensive single man-caused disaster to ever strike National Parks (U.S. National Park Service, 1990). Coastal winds and currents transported the oil slick southwest along the north shore of the Gulf of Alaska (Figure 10). The storm-tossed crude oil degraded and weathered into an oil-and-water emulsion called "mousse". These viscous mousse rafts continued southwest through the Shelikof Strait. In the end, oil from the *Exxon Valdez* stranded in various concentrations on the shores of Kenai Fjords National Park, Katmai National Park and Preserve, and Aniakchak National Monument and Preserve. KATM's coast received the greatest impact of the NPS units (U.S. National Park Service, 1990).

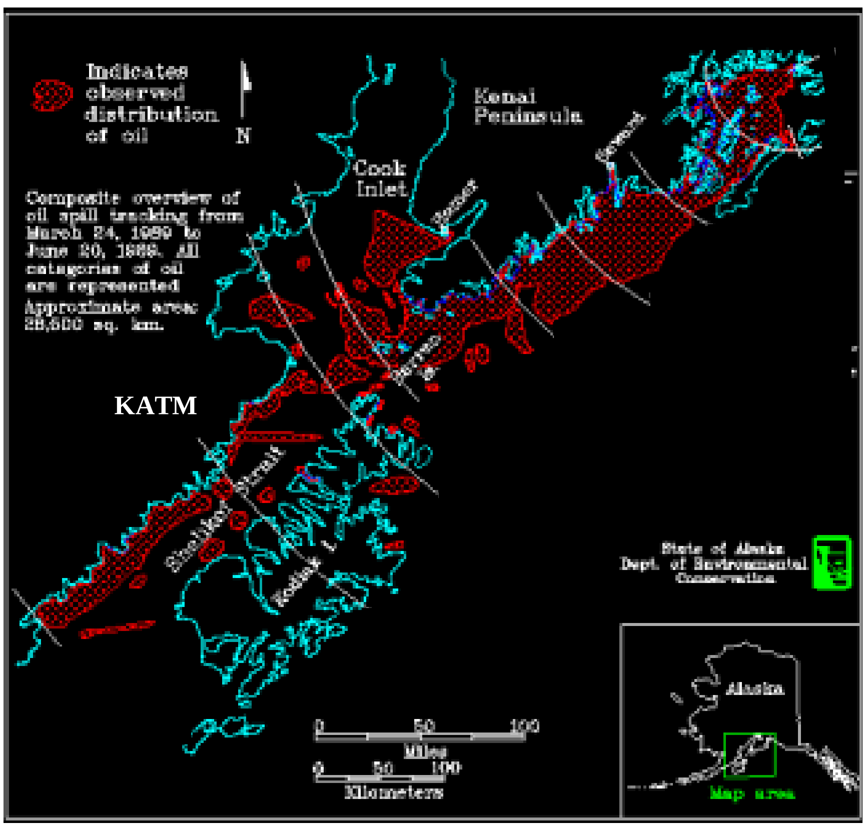


Figure 10. Observed Distribution of *Exxon Valdez* Oil Spill March 24 – June 20, 1989 (modified after Alaska Department of Environmental Conservation, 1999).

During the summers of 1989-1991, Exxon, with the cooperation of numerous state and federal resource management agencies, engaged in an unprecedented cleanup effort in an attempt to restore the oiled shoreline to an environmentally stable condition. In 1991, the federal government and the State of Alaska negotiated a monetary settlement for natural resource damage assessment claims against Exxon Corporation and Exxon Shipping Company. Through this monetary settlement, the NPS received funding to study the oil-related impacts on the coastal environments. The objective of this study is to determine the relative physical and chemical degradation rates of stranded oil mousse on Gulf of Alaska beaches and to correlate the degradation rate with geomorphological controls such as: energy regime, slope, aspect, substrate particle composition (Schoch, 1993).

Ten permanent transects were installed in 1989 on oil-impacted beaches along the Katmai National Park coastal shoreline. Data recording from each transect included characteristics and penetration of oil, and quantitative measurements of percent cover of oil, mineral and biota. Transects were permanently marked for future relocation and monitoring (Cusick, 1989).

In a 1990-1995 study, eelgrass (*Zostera spp*.) beds impacted by the *Valdez* oil spill were compared with reference (non-impacted) sites to assess possible impacts from the 1989 oil spill. Based on the study, injuries to eelgrass appeared to be slight and did not persist for more than a year after the spill (Dean et al., 1998).

In Alaska's 1996 Draft 305(b) Water Quality Assessment Report, Cape Douglas, located in the northeastern portion of KATM, was identified as impaired because aquatic resource injury is still evident due to the *Exxon Valdez* spill event (Alaska Department of Environmental Conservation, 1996a). For unknown reasons, this information was not included in Alaska's Final 1996 305(b) report (Alaska Department of Environmental Conservation, 1996b).

<u>Potential Oil and Gas Leasing in Lower Cook Inlet and Shelikof Straight</u>

The water resources of KATM are threatened by the potential exploration and development of oil and gas in Cook Inlet and Shelikof Straight under the Outer Continental Shelf program. Oil seeps and gas seeps in KATM were reported in the early 1900's by Martin (1905) and Smith (1925), respectively. During 1979 and 1980, the U.S. Geological Survey conducted field work to assess the petroleum potential of the Shelikof Strait based on outcrops in KATM. The results from this field work revealed promising petroleum exploration targets in the Shelikof Strait (Smith and Petering, 1981). Presently, both the state and federal governments are planning to sell oil and gas leases near the KATM coast (U.S. National Park Service, 1994).

Brooks River Area

The Brooks River Area, including a concessionaire facility and NPS operation collectively known as "Brooks Camp", is the most visited destination within the park. The camp lies 35 miles southeast of King Salmon near the Brooks River outlet, a 1.5-

mile long river that drains from Brooks Lake into Naknek Lake. Access to this seasonal use area is by float plane or boat. The Brooks River divides the area into two parts that lie north and south of the river. The north side of the river (North Camp) includes Brooks Lodge, guest cabins, visitor center, ranger station, auditorium, maintenance shop, incinerator building, generator building and numerous staff cabins and tent platforms. South Camp includes a former vehicle refueling area, park housing, and a bear viewing platform. In 1998, June-September, there were approximately 4171 overnight-stays in Brooks Lodge and 1269 overnight-stays in the campground (Brock, pers. comm., 1999).

The mouth of the Brooks River, which divides the north and south camps, is in a constant state of flux. It is unclear if the changes in river morphology are a response to the intensive use and development or result from natural processes (i.e., Naknek Lake long shore sediment transport) (U.S. National Park Service, 1994). Changes in natural riparian vegetation density and/or composition can produce unstable conditions for certain stream types (Rosgen, 1994). The heavy NPS/visitor use and development along the mouth of the Brooks River (i.e., decreased vegetation density) may contribute to the observed morphological changes in the river.

Petroleum Contamination

The primary and time-sensitive water resource issue at Brooks Camp is petroleum contamination of soils and ground water that resulted from a leaking NPS fuel distribution system. According to a U.S. National Park Service report (1997), this system, constructed in 1975, included two 8,000-gallon diesel underground storage tanks (USTs) that were connected by underground fiberglass piping to a 2000-gallon UST, a 500-gallon UST and numerous 62-gallon ASTs located at individual cabins. The 8,000-gallon tanks were filled from a fuel barge through an underground line that connected to a diesel fill box on the shore of Naknek Lake. At the southern portion of Brooks Camp, three 2,000-gallon USTs were used for bulk storage and to refuel vehicles. One 2000-gallon gasoline UST was located near the barge landing (immediately east of the Brooks River). Two other USTs, one gasoline, and one diesel were located in the vehicle parking area. In 1992, all USTs and underground piping failed to meet EPA tightness test standards.

Ground water at Brooks Camp occurs between 3 and 15 feet below ground surface in an unconfined aquifer. A site characterization performed in 1992 confirmed soils and ground water contamination from gasoline and diesel fuels and delineated a series of contamination plumes (Ecology and Environment, Inc., 1992). As a result, the leaking fuel distribution system was removed and a new system installed in 1993. Remediation of groundwater at Brooks Camp began in September 1998. Remediation will include limited soil excavation and on-site soil/ground water treatment (Ecology and Environment, Inc., 1993).

Two shallow ground water wells that provided potable water for Brooks Camp were impacted by the petroleum contamination. As a result, two new replacement wells were installed into the deeper bedrock aquifer (62 ft. depth at Brooks Camp and 110 ft. depth at Brooks Lake). Bill Heubner (pers. comm., 1998) stated that this deeper saturated unit was observed to be under pressure during the drilling operations. This suggests a confining layer exists under Brooks Camp, which would help minimize vertical migration of petroleum contamination into the deeper aquifer. A clayey sand that is reported to underlie the entire site is probably the confining unit that separates the shallow water table aquifer from the bedrock aquifer (U.S. National Park Service, 1997).

Wastewater Management

Disposal of fish wastes has been a problem in the past at Brooks Camp. A past practice of disposing ground fish wastes into the septic system contributed to system failures and increased maintenance. The cleaning of fish at Brooks Camp is no longer allowed. In 1995, a new leach field was installed at Brooks Camp. In 1996, a new sand filter was installed into the septic system, which recently failed in 1998. According to Richard Sherman (pers. comm., 1998), the septic system needs a larger leach field to function adequately with the current seasonal loading. Expansion of the leach field is limited due to the numerous archeological sites at Brooks Camp. One option for consideration would be to convert wastewater treatment to an above-ground system. Glacier Bay National Park & Preserve has installed such a system for their park facilities.

It should also be noted that in King Salmon, KATM's wastewater lines have recently been connected to the city's wastewater treatment system (Sherman pers. comm., 1998).

Valley Road Management

Valley Road is a 23-mile gravel road that connects Brooks Camp with the Valley of Ten Thousand Smokes. This road is used daily during the summer by a concessionaire to transport visitors via bus from Brooks Camp to the Valley of Ten Thousand Smokes. The road crosses two Margot Creek tributaries at mile 12.2 and 16.0, and Margot Creek at mile 16.8 (U.S. National Park Service, 1994). KATM staff maintains these three stream road crossings by excavating gravel upstream and/or downstream from each respective crossing and transporting the material to the existing roadbed (Ferguson, pers. comm., 1998). According to Kathleen Kuná of the U.S. Army Corps of Engineers (pers. comm., 1998), the park currently has a permit for annual maintenance of these stream crossings that is valid until 2007. Approximately three miles separate the first stream crossing from Margot Falls, where significant numbers (> 5000 in 1991) of sockeye salmon spawn. Impacts from Valley Road maintenance on salmon spawning habitat, if any, are unknown (U.S. National Park Service, 1994).

A multi-million dollar NPS project, in cooperation with the Federal Highways Administration, to repair and improve Valley Road was active during the summer of 1998. The Valley Road project is incomplete with only six miles of the 23-mile project completed. Plans are underway to complete the work and revegetate disturbed sites.

Wetlands Management

The NPS implements a “no net loss of wetlands” policy. Executive Order 11990 directs the NPS: 1) to provide leadership and to take action to minimize the destruction, loss, or degradation of wetlands; 2) to preserve and enhance the natural and beneficial values of wetlands; and 3) to avoid direct or indirect support of new construction in wetlands unless there are no practicable alternative to such construction and the proposed action includes all practicable measures to minimize harm to wetlands (U.S. National Park Service, 1998a).

Director’s Order 77-1: *Wetlands Protection* requires the NPS to conduct or obtain wetland inventories within each park unit. Presently, KATM does not have an adequate inventory of wetlands within its boundaries to assist proper NPS planning with respect to management and protection of wetland resources. In FY98, KATM was unsuccessful in seeking funding for a wetlands mapping project of KATM’s coast. According to this project statement, visitation is beginning to increase and several commercial operators have recently requested permits for mooring buoys along the coast. The coast is already on the schedule for several major tour operations and the current impacts from these activities to coastal wetlands, if any, is unknown. KATM’s coastal wetlands provide important habitat for arthropods, molluscs, echinoderms, fish, birds and mammals (U.S. National Park Service, 1998b). It is important for the NPS to establish baseline wetland information to assist with separating anthropogenic impacts from natural processes.

The U.S. Fish & Wildlife Service (USFWS) has developed National Wetlands Inventory (NWI) maps for portions of Alaska. Unfortunately, the current NWI coverage does not include KATM (U.S. Fish and Wildlife Service, 1998a).

LaPerriere (1996) elevated the need for water quality and biota studies (i.e., vascular aquatic plant productivity and function) on the small lakes and ponds associated with wetlands in KATM. The influence of wetlands on nearby lakes and streams in the park is not understood, especially regarding the nutrient dynamics.

Spill Contingency Planning

The potential for petroleum spills along KATM’s Shelikof Strait coast will continue to threaten natural resources as long as mineral interests exist in the region. The NPS is severely limited in qualified personnel, spill response equipment, and baseline natural resource information to effectively respond to petroleum spills in KATM. Emergency response to a major spill (i.e., *Exxon Valdez*) requires expertise and field equipment that extends beyond the capabilities of the NPS. As a result, a communication process (i.e., Spill Prevention Control and Countermeasure Plan (SPCC)) should be completed so designated park staff can request assistance from qualified federal, state and/or private contractor personnel in a time-efficient manner.

KATM manages numerous fuel storage systems (i.e., heating oil, diesel, gasoline) to accommodate visitor and NPS operations. Due to petroleum contamination problems encountered with the underground fuel storage system within the Brooks River Area and federal compliance requirements, KATM is in the process of closing all existing underground fuel systems and upgrading to double-walled above-ground storage tank systems (Sherman, pers. comm., 1998). Although this effort will greatly reduce the threat of accidental releases, the potential for petroleum contamination from NPS operations will still exist. For example, fuel contamination from float planes and motorboats have been observed along the Naknek Lake shore at Brooks Camp. In 1990, a fuel spill resulted from an accidental dropping of a drum from a sling-load at Kukak Bay (U.S. National Park Service, 1994). Gasoline and heating fuels are transported via the park tanker vessel 30 miles across Naknek Lake to Brooks Camp throughout the summer months. Thus, there is the potential for an accidental fuel release during the fuel-loading process, transportation of fuels across Naknek Lake, and fuel-unloading process of the tanker at Brooks Camp.

KATM conducts spill response exercises with staff each spring (Sherman, pers. comm., 1998) and there is a 1989 Oil and Hazardous Substance Spill Prevention and Emergency Response Plan in place. According to a 1993 trip report prepared by Roy Irwin (NPS-Water Resources Division), KATM does not have a spill plan up to the 1990 Oil Pollution Act (OPA) standards, which established new requirements for oil spill response and natural resource damage assessment.

Water Rights

Alaska is relatively young with respect to water laws. The State uses the Prior Appropriation Doctrine to allocate water. This doctrine establishes a right to the use of water based upon "first in time, first in right". Water rights are given priority based upon the date of first use. Federal agencies can apply for and be granted instream flow water rights (Hansen, pers. comm., 1999). It allows federal agencies to apply for and receive instream water rights. Regulations were updated in 1991 (Bayha et al., 1997). The objectives of the Department of Interior's water rights programs in Alaska are to acquire and protect water rights for lands managed by the respective Department of Interior Bureau's. It is the policy of the NPS to obtain and protect water rights by assertion of prior appropriation rights recognized under state law or federal rights mandated by Congress for quantities determined to be the minimum amount necessary for the purpose of the park units. The current data for quantifying water rights at NPS units in Alaska is insufficient. For example, the state of Alaska requires 5 years of stream-gaging information to support instream water right applications. Additionally, State law requires biological, recreational, or water quality data to justify the need for the requested instream water rights. (U.S. Department of the Interior, 1998). This further supports some of the baseline information needs presented earlier in this report.

Coordination

Today, multi-agency coordination is essential in all Alaskan park units to effectively monitor and manage the natural resources. Unfortunately at KATM, it is difficult to establish long-term coordination relationships with other agencies. One reason is because Alaska is so large that attention cannot be directed to every watershed in the State due to limited resources. As previously stated, in 1995 Alaska had an average of one stream gaging station per 8,395 mi^2, compared to an average of one gage per 336 mi^2 in the lower 48 states (Bayha, et al., 1997). Another reason is that KATM, along with other undeveloped areas in Alaska, lacks the time-sensitive water resource issues or impacts, which typically drive information-gathering projects. The one exception at KATM is the *Exxon Valdez* 1989 oil spill where multi-agency monitoring projects supported by a monetary settlement are on-going along the Shelikof Strait coastline.

In FY99, the U.S. Geological Survey and NPS have implemented 35 partnership projects in national park units. As mentioned earlier in the report, one of these partnership projects is currently being implemented on the Alagnak Wild and Scenic River. This is a result of the Clean Water and Watershed Restoration Initiative, where the NPS and U.S. Geological Survey are working together to reduce the backlog of NPS water quality monitoring and assessment needs.

The U.S. Geological Survey National Water-Quality Assessment (NAWQA) Program has one study unit in Alaska, the Cook Inlet Basin Study Unit (Figure 11). Initiated in 1996, the Cook Inlet Study Basin includes the extreme northeastern part of KATM (U.S. Geological Survey, 1997). Funded by the NPS Water Resources Division as a demo NPS/USGS partnership project, a synoptic investigation was conducted by the U.S. Geological Survey on the Kamishak River in KATM, which is located within the Cook Inlet Study Basin (Long, pers. comm., 1999). There have been no permanent NAWQA sampling sites established within the park (Frenzel, pers. comm., 1998). The U.S. Geological Survey's water quality concerns in the Cook Inlet Basin are related primarily to salmon spawning and documentation of conditions in relatively undeveloped environments.

The Alaska Watershed Monitoring and Assessment Project (AWMAP) is a statewide water quality monitoring project involving local, state, and federal agencies; industry; schools; University of Alaska; and other entities conducting water quality monitoring. The AWMAP framework was developed cooperatively between the Alaska Department of Environmental Conservation and the U.S. Environmental Protection Agency. The AWMAP objectives include (Alaska Department of Environmental Conservation, 1996a):

1. Develop a network of individuals interested in and/or involved in the collection of environmental data.
2. Maintain current information on existing monitoring stations and programs in Alaska.
3. Develop a list of environmental indices (biological, chemical and physical) for short- and long-term monitoring that will allow for the assessment of water quality contaminants in Alaska.
4. Coordinate reporting of existing data and receipt of future data from existing monitoring stations in Alaska.
5. Develop a common set of criteria against which information will be evaluated.

6. Develop recommendations annually for locations and types of additional monitoring stations required to meet the overall objectives of monitoring water quality in Alaska's diverse environments.
7. Issue alternate year reports to the Section 305(b) reporting process on status of Alaska's Watershed Monitoring and Assessment Network.

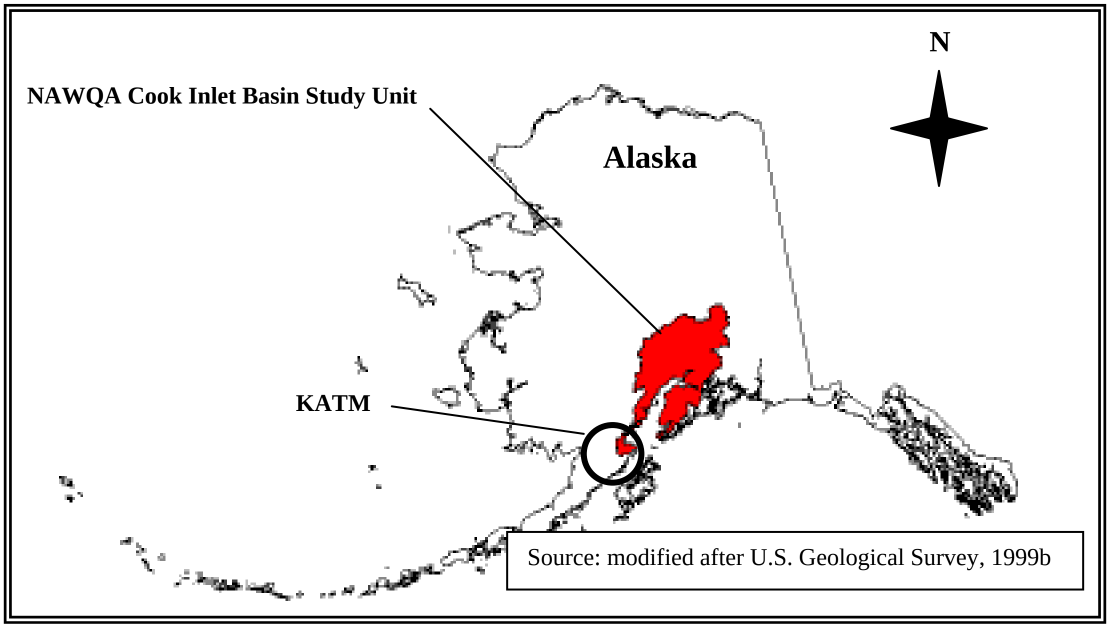


Figure 11. U.S. Geological Survey NAWQA Cook Inlet Basin Study Unit.

In 1995, the Alaska Department of Environmental Conservation and the U.S. Environmental Protection Agency sponsored the formation of a workgroup to develop a statewide approach for improved watershed management. The workgroup's objective is to create a process that could satisfy many of the regulatory requirements of the Federal Clean Water Act. These include producing Total Maximum Daily Loads (TMDLs) on a watershed basis, coordinating wastewater discharge permits within a watershed, and preparing a comprehensive list of impaired water bodies throughout the State (Alaska Department of Environmental Conservation, 1997). It is important for the NPS to be actively involved in these and other similar efforts to effectively voice their natural resource needs and contribute to the information databases. The Alaska Department of Environmental Conservation has expressed an interest in coordinating with KATM and other NPS units in Alaska on water resource issues (Decker, pers. comm., 1999).

A key element for the limited hydrologic data collected in Alaska is data coordination. The Interagency Hydrology Committee for Alaska (IHCA) comprises federal, state, and local agencies concerned with water resources. The IHCA ensures that data are collected in an efficient and effective manner, without duplication of efforts. A Geographic

Information System (GIS) for Alaska lands and waters is currently being developed by the Alaska Geographic Data Committee, a joint Federal and State effort (U.S. Department of the Interior, 1998).

KATM has had some success in coordinating water-related projects with other agencies (i.e., NPS/USGS Alagnak Project) and universities. In 1996, the NPS and U.S. Fish and Wildlife Service entered into an interagency agreement, which specified that the U.S. Fish and Wildlife Service would conduct a baseline study of potential hydrocarbon contamination within selected waters in KATM. A final report that summarizes the findings from this effort was recently completed (Johnson and Berg, 1999). Also in 1996, the University of Alaska Fairbanks completed the report, *Water Quality Inventory and Monitoring – Katmai National Park and Preserve* as part of an Interagency Agreement with the NPS (LaPerriere, 1996). KATM should continue to encourage these and other partnerships to meet the information needs of the park.

RESOURCES MANAGEMENT STAFFING AND PROGRAMS

The KATM Natural Resource Management Division staff is currently comprised of four permanent positions and two vacant positions as indicated in the organizational structure presented in Figure 12. The Division is augmented by anywhere between 5-15 seasonal project support personnel each year including, biological science technicians, Student Conservation Association resource assistants, student interns, graduate students and volunteers. The Chief of Resource Management reports directly to the Katmai Group Unit Manager and is responsible for the park's natural resource management program, geographic information system and environmental compliance. The Katmai Group consists of Katmai National Park and Preserve, Aniakchak National Monument and Preserve and the Alagnak Wild River unit areas. The Katmai Group and Lake Clark National Park and Preserve (LACL) were administratively linked in 1995 as part of the Servicewide reorganization initiative. The Unit Manger for the Katmai Group reports to the Superintendent who is also responsible for LACL and is based in Anchorage.

In 1993, one research grade scientist position (wildlife/bear biologist) was transferred to the USGS-Biological Resources Division. The park's coastal management biologist (CMB) left in 1997 and remains unfilled. All positions indicated, with the exception of the CMB position, are based at the park's field headquarters in King Salmon. The CMB position is based in Kodiak. The Kodiak resources management operation was temporarily suspended in 1999 after the motorboat operator transferred and the CMB position remained unfilled. It is indefinite when park satellite operations in Kodiak will resume, although it is a high park priority.

Current projects in the park that directly or indirectly relate to water resources have already been summarized in the preceding sections of this report. The numerous fisheries projects that focus on management and species population dynamics and habitat will be fully detailed and addressed in a Fisheries Management Plan expected to be finalized in 2000. Considering the immensity of KATM water resources and the complex issues associated with these resources, the park has forged close working relationships with a wide variety of federal, state and local agencies and other coalitions in an effort to collaborate on effective water resources management. Included are the USGS-Biological Resources Division, USGS-Water Resources Division, Bureau of Land Management, Alaska Depart of Fish and Game, Alaska Department of Environmental Conservation, Bristol Bay Borough and various private organizations and individuals to numerous to list here. Collectively, all these sources have expressed a sincere interest to assist the park preserve its riparian, lacustrine and coastal habitats and prevent degradation to the parks water resources that so many park biota are vitally dependant upon for their very survival. As recommended by this document, the park is committed to seek funding support to complete a Water Resource Management Plan (WRMP). A WRMP will enable better understanding of the park's water resources, result in well defined water resources management goals and measurable management objectives, develop project statements, prioritize actions and facilitate the necessary collaborative water resources management process described throughout this document.

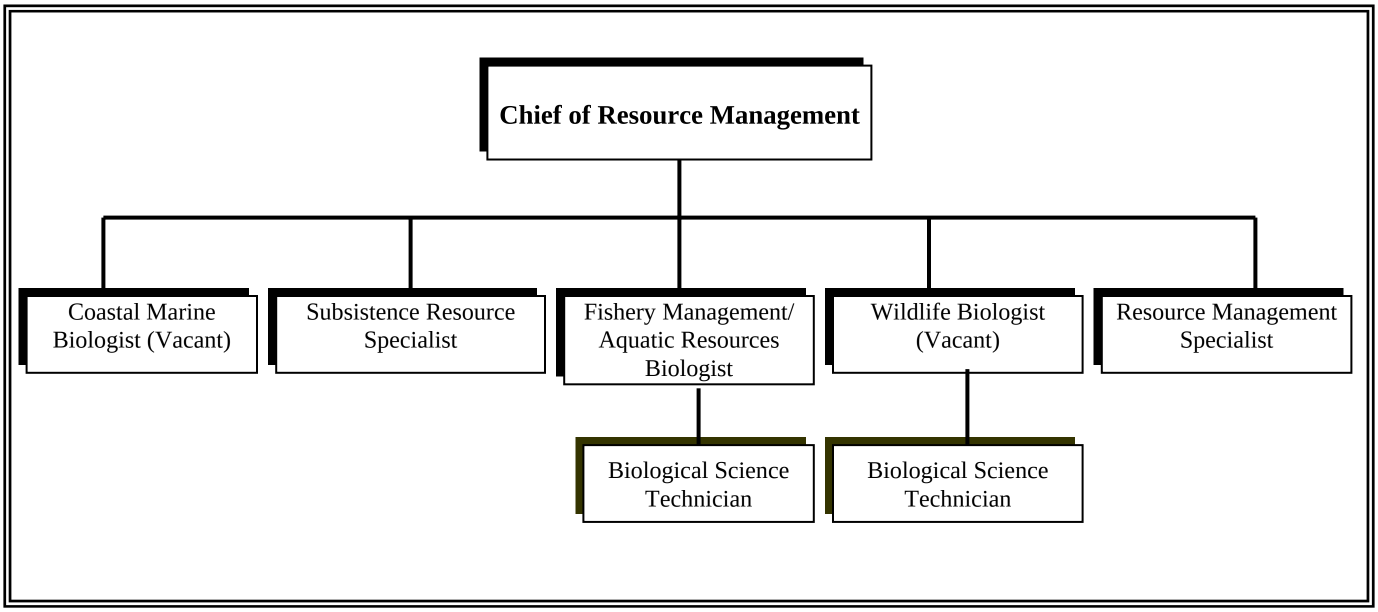


Figure 12. Katmai National Park and Preserve, Natural Resources Program: Organization and Structure.

RECOMMENDATIONS

The water-related issues and natural resource data presented in this report are supported through regional and local research and monitoring efforts. Identification of available water resource information (i.e., what has or has not been done at KATM?) has also contributed toward exposing the “data gaps”, which translates to natural resource needs for KATM. The natural resource needs presented in this report are summarized below:

- Baseline information on water resources.
  - establish permanent gaging stations in the larger streams.
  - establish permanent water quality monitoring stations in the streams and lakes.
  - bathymetrically map large lakes as needed to compliment future studies and establish GPS-fixed stations in the deepest location of each lake to be monitored.
  - conduct phytoplankton and aquatic invertebrate species distribution studies.
  - correlate park’s aquatic ecology needs with the annual nutrient loading from salmon.
  - establish meteorological monitoring stations in remote areas, in cooperation with the U.S. National Weather Service.
  - assist the U.S. Fish and Wildlife Service to develop National Wetlands Inventory (NWI) maps for KATM.
  - accumulate appropriate data (i.e., stream flow, water quality, biological, recreational) to support instream water rights.

- Internal Management
  - prepare a Spill Prevention Control and Countermeasure (SPCC) Plan, that meets the 1990 OPA standards, to properly address routine facilities operations (i.e., fuel system management, waste management) and spill response procedures.
  - monitor the influence from Valley Road maintenance on salmon habitat below Margot Falls.
  - continue to monitor the remedial efforts on petroleum contamination at Brooks Camp.
  - evaluate options for wastewater management at Brooks Camp.

- Recreational Management
  - evaluate streambed morphology impacts from visitor use on American Creek.
  - establish continuous bank erosion monitoring on the Alagnak Wild River.
  - prepare a Fisheries Management Plan.
  - better document recreational fishery activities and harvest.
  - conduct backcountry facility contamination assessments at Grosvenor Lake Lodge, Lake Camp, and Kulik Lodge to follow-up on previous work.

- Coastal Issues
  - continue to assess recovery of coastal environments and biota impacted by the 1989 *Exxon Valdez* oil spill.
  - monitor expansion of oil and gas exploration in Cook Inlet and the Shelikof Strait.
  - evaluate visitor use impacts on coastal water resources (i.e., wetlands).
  - coordinate with State of Alaska concerning coastal planning work.

- Coordination
  - continue to coordinate and assist in the multi-agency coastal monitoring projects to evaluate impacts and recovery of natural resources from the 1989 *Exxon Valdez* oil spill.
  - coordinate with the U.S. Geological Survey's effort to monitor erosion along the Alagnak Wild River and synoptic studies associated with the Cook Inlet NAWQA program (i.e., Kamishak River).
  - coordinate with the Soil and Conservation Service to assist in the establishment of snow depth survey stations.
  - continue to participate in the Alaska Department of Environmental Conservation and U.S. Environmental Protections Agency's state-wide effort to improve watershed management.
  - initiate cooperative efforts between KATM and the Alaska Department of Environmental Conservation, supported by Clean Water Act funding, that address high priority water-related issues.

The political and environmental complexity of the park's issues elevates the need for strong *coordination*, *planning*, and *management* by the NPS and other stakeholders to adequately protect and preserve KATM's water resources. Essential to developing these three important needs is to expand upon the information contained in this scoping report by producing a more comprehensive Water Resources Management Plan (WRMP) for the park.

A WRMP will provide a more detailed description of the issues presented in this report, while including an overview of existing state and federal legislation that pertains to the park's water resources. The plan will also include recommended actions (project statements) for the park's Resource Management Plan that addresses these, and possibly other, high-priority issues. Project statement development should begin with the begin with the natural resource needs outlined in this section. These project statements will define the specific problem(s) and recommended action(s), including a representative budget, that can compete for future internal and external funding calls.

The WRMP process will encourage other stakeholders to participate with the NPS during and after plan development. Many of the issues presented in this report extend beyond NPS boundaries; thus, it is important to recognize the fact that multi-agency communication and coordination are essential to successfully manage KATM's water resources.

The park is encouraged to place a high priority in seeking funds, both internally and externally, to expand its resource management program, and to develop a strong WRMP. It is estimated that a WRMP for the park will take two years to complete and cost approximately $50,000. Until a WRMP is prepared for KATM, components of this scoping report should be used in the development of time-sensitive management strategies and project statements relating to water resource issues.

LITERATURE CITED

Alaska Department of Environmental Conservation. 1996a. Alaska's Draft 1996 Section 305(b) Water Quality Assessment Report (Public Review Draft). Division of Air and Water Quality. Juneau, AK. 52 pp. + appendices.

Alaska Department of Environmental Conservation. 1996b. Alaska's 1996 Water Quality Assessment Report. Clean Water Act Section 305(b) and Section 303(d). Division of Air and Water Quality. Juneau, AK. 30 pp. + appendices.

Alaska Department of Environmental Conservation. 1997. Watershed Partnerships in Alaska. Alaska Dept. of Environmental Conservation, Division of Air and Water Quality, Juneau, AK. 16 pp.

Alaska Department of Environmental Conservation. 1999. Distribution of Exxon Valdez Oil Spill March 24 – June 20, 1989. http://www.alaska.net/`ospic/akmap.html.

Alaska Department of Natural Resources. 1999. State Policy on Navigability. http://www.dnr.state.ak.us/land/policy.html.

Alderson, J. 1999. Personal Communication. National Park Service, Alaska System Support Office. Anchorage, AK.

Allan, J.D. 1995. Stream Ecology, Structure and Function of Running Waters. School of Natural Resources and Environment, University of Michigan. Chapman & Hall USA, New York, NY. pp. 303-302.

Allen, E.T. and Zies. E.G. 1923. A Chemical Study of the Fumaroles of the Katmai Region. National Geographic Society, Contrib. Tech. Pap., Katmai Series, 2:75-155.

Bayha, K., S. Lyons, M.L. Harle. 1997. Strategic Plan for Water Resources Branch. U.S. Department of Interior, Fish and Wildlife Service, Region 7, Division of Realty, Water Resources Branch, WRB 97-1. Anchorage, AK, 25 pp.

Belland, R.J. and D.H. Vitt. 1995. Bryophyte Vegetation Patterns along Environmental Gradients in Continental Bogs. Ecosystem 2:385-407.

Berg, E., K Susumu, and J. Kiele. 1967. Preliminary Determination of Crustal Structure in the Katmai National Monument, Alaska. Bull. Seismological Soc. Am. 57(6): 1367-1392.

Bodeau, J. 1992. Katmai National Park and Preserve, Alaska. Greatland Graphics and the Alaska Natural History Association. Anchorage, Alaska. 11 p.

Brock, B. 1999. Personal Communication. National Park Service, Katmai National Park and Preserve. King Salmon, AK.

Buck, E.H., C. Bowden, J. Baldridge, and W.J. Wilson. 1978. Bibliography, Synthesis, and Modeling of Naknek River Aquatic System Information. Report for U.S. Dept. of Interior, National Park Service, Pacific Northwest Region, Seattle, Washington. Arctic Environmental Information and Data Center, University of Alaska, Anchorage, AK. 244 pp.

Burke, C.A. 1965. Geology of the Alaska Peninsula – Island Arc and Continental Margin. Geol. Soc. Am. Mem. 99, 250 p.

Cameron, R.E. 1970. Soil Microbial Ecology of Valley of 10,000 Smokes, Alaska. Jour. Ariz. Acad. Sci. 6(1): 11-40.

Clark, R. 1999. Personal Communication. National Park Service, Katmai National Park and Preserve. King Salmon, AK.

Cowardin, L.M., V. Carter, F.C. Golet, and E.T. LaRoe. 1979. Classification of Wetlands and Deepwater Habitats of the United States. U.S. Dept. Interior – Fish and Wildlife Service, FWS/OBS-79/31.

Curtis, G.H. 1968. The Stratigraphy of the Ejecta from the 1912 Eruption of Mount Katmai and Novarupta, Alaska. Geol. Soc. Am. Mem, 116:153-210.

Cusick, J.A. 1989. NPS Permanent Oil Transects. National Park Service, Katmai National Park and Aniakchak National Monument. King Salmon, AK

Dahlberg, M.L 1972. Naknek System Red Salmon Studies. Plan of Operation, April 1972 – March 31, 1973. U.S. National Marine Fisheries Service, Auke Bay Biological Laboratory. Intradepartmental memo. pp. 1-8

Davis, W.S., B.D. Snyder, J.B. Stribling and C. Stoughton. 1996. Summary of State Biological Assessment Programs for Streams and Wadeable Rivers. EPA 230-R-96-007. U.S. Environmental Protection Agency; Office of Policy, Planning, and Evaluation: Washington, D.C. pp. 1-1, 3-10.

Dean, T.A., M.S. Stekoll, S.C. Jewett, R.O. Smith and J.E. Hose. 1998. Eelgrass (*Zostera marina* L.) in Prince William Sound, Alaska: Effects of *Exxon Valdez* Oil Spill. [In] Marine Pollution Bulletin. 36 (3): 201-210.

Dearborn, L.L. 1979. Potential and Developed Water-Supply Sources in Alaska. [In] Jour. of the Alaska Geol. Soc. 1981. Anchorage, AK. 1:1-11.

Decker, E. 1999. Personal Communication. Alaska Department of Environmental Conservation. Juneau, AK.

Deschu, N. 1999. Personal Communication. National Park Service, Alaska System Support Office. Anchorage, AK.

Dorava, J.M. 1998a. Alagnak River Trip Report, July 1998. U.S. Geological Survey, Water Resources Division. Anchorage, AK. 6 pp.

Dorava, J.M. 1998b. Alagnak River Trip Report, September 1998. U.S. Geological Survey, Water Resources Division. Anchorage, AK. 2 pp.

Dorava, J.M. and A.M. Milner. 1999. Effects of Recent Volcanic Eruptions on Aquatic Habitat in the Drift River, Alaska, USA: Implications at Other Cook Inlet Region Volcanoes. Environmental Management 23(2):217-230.

Ecology and Environment, Inc. 1992. Site Characterization at Brooks Camp, Katmai National Park and Preserve, Alaska. Contract No. DACA85-91-D-0003. Anchorage, AK. 10-2 pp. + appendices.

Ecology and Environment, Inc. 1993. Design Analysis/Technical Specifications/Cost Estimate Groundwater Remediation (35%) at Brooks Camp, Katmai National Park and Preserve, Alaska. Contract No. DACA85-91-D-0003. Anchorage, AK. 2-3 pp. + appendices.

Eicher, Jr., G.J. and G.A. Rounsefell. 1957. Effects of Lake Fertilization by Volcanic Activity on Abundance of Salmon. Limnology and Oceanography. II (2):70-76.

Fenner, C.N., 1920. The Katmai Region, Alaska, and the Great Eruption of 1912. Jour. of Geol. 28:596-606.

Fenner, C.N., 1922. Evidences of Assimilation During the Katmai Eruption of 1912. Bull. Geol. Soc. Am. 33:129.

Fenner, C.N., 1923. The Origin and Mode of Emplacement of the Great Tuff Deposit of the Valley of Ten Thousand Smokes. National Geographic Society, Contri. Tech. Pap. Katmai Series 1:1-74.

Fenner, C.N., 1925. Earth Movements Accompanying the Katmai Eruption II. J. Geol. 33(3):193-223.

Fenner, C.N. 1926. The Katmai Magmatic Province. Jour. Geol. 35:673-772.

Fenner, C.N. 1950. The Chemical Kinetics of the Katmai Eruption. Am. Jour. Sci. 248:593-627.

Ferguson, T. 1998. Personal Communication. Katmai National Park and Preserve, Maintenance Division. King Salmon, AK.

Frenzel, S. 1998. Personal Communication. U.S. Geological Survey – Water Resources Division, National Water-Quality Assessment Program. Anchorage, AK.

Gilbert, C. 1999. Personal Communication. National Park Service, Alaska System Support Office. Anchorage, AK.

Goldman, C.R. 1960. Primary Productivity and Limiting Factors in Three Lakes of the Alaska Peninsula. Ecological Monographs 30:207-230.

Griggs, R.F. 1917. The Valley of Ten Thousand Smokes. The National Geographic Magazine. National Geographic Society, Washington D.C. 31(1):13-68.

Griggs, R.F. 1918. The Valley of Ten Thousand Smokes. The National Geographic Magazine. National Geographic Society, Washington D.C. 33(2):137.

Griggs, R.F. 1920. The Recovery of Vegetation at Kodiak. Ohio State University Bull. 24(15): 1-57.

Griggs, R.F. 1922. The Valley of Ten Thousand Smokes. National Geographic Society, Washington DC. 340 p.

Gunther, A.J. 1992. A Chemical Survey of Remote Lakes of the Alagnak and Naknek River Systems, Southwest Alaska. U.S.A. Arctic and Alpine Research 24(1):64-68.

Hamon, T. 1999. Personal Communication. National Park Service, Katmai National Park and Preserve. King Salmon, AK.

Hansen, B. 1999. Personal Communication. National Park Service, Water Resources Division, Water Rights Branch. Ft. Collins, CO.

Hazardous Materials Technical Center. 1989. Installation Restoration Program, Preliminary Assessment, Naknek Recreational Camps, Alaska. The Dynamac Building (Contract No. DLA-900-82-C-4426). Rockville, MD. ES-2, ES-3.

Heard, W.R., R.L. Wallace, and W.L. Hartman. 1969. Distributions of Fishes in Fresh Water of Katmai National Monument, Alaska, and their Zoogeographical Implications. U.S. Fish and Wildlife Service, Special Scientific Report-Fisheries 590. 20 pp.

Heubner, B. 1998. Personal Communication. National Park Service, Alaska System Support Office. Anchorage, AK.

Hildreth, W. 1983. The Compositionally Zoned Eruption of 1912 in the Valley of Ten Thousand Smokes, Katmai National Park, Alaska. In: S. Aramaki and I. Kushiro (Eds), Arc Volcanism. J. Volcanol. Geotherm. Res., 18:1-56.

Hildreth, W. 1987. New Perspectives on the Eruption of 1912 in the Valley of Ten Thousand Smokes, Katmai National Park, Alaska. Bull. of Volcanology 49:680-693.

Horton, G.E. 1994. Effects of Jet Boats on Salmonid Reproduction in Alaskan Streams. (unpub. Master thesis) University of Fairbanks. Fairbanks, AK. pp. 12, 71.

Irwin, R. 1993. Trip Report for Travel to Alaska Regional Office, Katmai National Park, and Lake Clark National Park on August 5-12, 1993. September 13, 1993 Memorandum. National Park Service, Water Resources Division, Ft. Collins, CO. 8 pp.

Johnson, P. and C. Berg. 1999. Baseline Hydrocarbon Study: Katmai National Park and Preserve Final Report. U.S. Fish and Wildlife Service, Alaska Regional Office, Ecological Services Environmental Contaminants Program. Anchorage, AK. 20 pp. + tables, figures, and appendix.

Jope, K.L. and L.A. Welp. 1987. Monitoring Resource Conditions Related to Commercial Use On American Creek. National Park Service, Katmai National Park and Preserve, King Salmon, AK. 30 pp.

Karr, J.R. 1991. Biological Integrity: A Long-Neglected Aspect of Water Resource Management. Ecological Applications 1:66-84.

Karr, J.R. 1993. Defining and Assessing Ecological Integrity: Beyond Water Quality. Environmental Toxicology and Chemistry 12:1521-1531.

Kavanagh, R. 1999. Personal Communication and Figure 8. National Park Service, Alaska System Support Office. Anchorage, AK.

Keith, T.E.C. 1984. Preliminary Observations on Fumarole Distribution and Alteration, Valley of 10,000 Smokes Alaska. [In] K.M. Reed and S. Bartsch-Winkler (eds.), U.S. Geological Survey in Alaska: Miscellaneous Geologic Research 1982. U.S. Geol. Surv. Circ. 939:82-85.

Keith, T.E.C. 1986. Distribution of Hydrothermal Alteration Associated with Novarupta Caldera, Katmai National Park, Alaska. EOS, Transactions, American Geophysical Union 67(44):1246.

Keith, T.E.C., J.M. Thompson, R.A. Hutchinson, L.D. White, M. Nathenson. 1990. Geochemistry of Streams and Springs, Valley of Ten Thousand Smokes, Katmai National Park, Alaska. EOS, Transactions, American Geophysical Union 71(43): 1691.

Keith, T.E.C., 1991. Fossil and Active Fumeroles in the 1912 Eruptive Deposits, Valley of Ten Thousand Smokes, Alaska. Jour. Volcanol. Geotherm. Res., 45:227-244.

Keller. S.A. and H.N. Reiser. 1959. Geology of the Mount Katmai Area Alaska. U.S. Department of the Interior, U.S. Geological Survey, Bul. 1058-G, U.S. Govt. Printing Office, Washington D.C. 261-298 pp.

Kienle, J. and S.E. Swanson. 1983. Volcanism in the Eastern Aleutian Arc: Late Quaternary and Holocene Centers, Tectonic Setting and Petrology. [In] B.H. Baker and A.R. McBirney (eds.), Jour. of Volcanology and Geothermal Research 17:393-432.

Kline, T.C., J.J. Goering, O.A. Mathisen, and P.H. Hoe. 1990. Recycling of Elements Transported Upstream by Runs of Pacific Salmon: ^{15}N and ^{13}C Evidence in Sashin Creek, Southeastern Alaska. Can. Jour. Fish. Aquat. Sci. 47:136-144.

Kuná, K. 1998. Personal Communication. U.S. Army Corps of Engineers. Anchorage, AK.

LaPerriere, J.D. 1996. Water Quality Inventory and Monitoring – Katmai National Park and Preserve. University of Alaska, Alaska Cooperative Fish and Wildlife Research Unit, Fairbanks, AK. 150 pp.

LaPerriere, J.D. 1997. Limnology of Two Lake Systems of Katmai National Park and Preserve, Alaska: physical and chemical profiles, major ions, and trace elements. Hydrobiologia 354:89-99.

Long, B.A. 1999. Personal Communication. National Park Service, Water Resources Division, Water Operations Branch. Ft. Collins, CO.

Mandel, S. and Z.L. Shiftan. 1981. Groundwater Resources, Investigation and Development. Academic Press, Inc. New York, NY. pp. 23-42

Martin, G.C. 1905. Notes on the petroleum fields of Alaska, [In] Brooks. Report on progress of investigations of mineral resources in Alaska in 1904. U.S. Geol. Survey. Bull. 259: 138.

McClenahan, P.L. 1993. Hazardous Waste Site Characterization Level I, Grosvenor Lodge, Katmai National Park. National Park Service, Katmai National Park and Preserve, Aniakchak National Monument and Preserve. King Salmon, AK. 5 pp.

Merrell, T.R., Jr. 1964. Ecological Studies of Sockeye Salmon and Related Limnological and Climatological Investigations, Brooks Lake, Alaska, 1957. U.S. Fish and Wildlife Service. Special Scientific Report-Fisheries 456. 66 pp.

Montague, R.W. (ed.) 1974. Exploring Katmai National Monument and Valley of Ten Thousand Smokes. Alaska Travel Publications Inc., Anchorage, AK. 77 p.

Muller, E.H. and P. Ward. 1966. Savonoski Crater, Katmai National Monument, Alaska, 1964. NSF Grant No. GP-2821. Dept. of Geology, Syracuse University & Lamont Geological Observatory, Columbia University. 39 pp.

National Oceanic and Atmospheric Administration. 1998. 1961-1990 Climatic Data for King Salmon, AK and Kodiak, AK. http//www.ncdc.noaa.gov/ol/climate/online/ccd/(meantemp.html) & (nrmlprcp.html).

Natural Resources Conservation Service. 1998. Status of Soil Surveys, October 1998. U.S. Department of Agriculture. http//www.statlab.iastateedu/soils/soildiv/sslists/map.html.

Nelson, G.L. 1998. Personal Communication. U.S. Geological Survey, District Chief. Anchorage, AK.

Pinney, D.S. and J.E. Begét, 1991. Deglaciation and Latest Pleistocene and Early Holocene Glacier Readvances on the Alaska Peninsula: Records of Rapid Climate Change Due to Transient Changes in Solar Intensity and Atmospheric CO_2 Content? [In] International Conference on the Role of the Polar Regions in Global Change: Geophysical Institute and Center for Global Change and Artic System Research, University of Alaska, Fairbanks. pp. 634-640.

Plafkin, J.L., M.T. Barbour, K.D. Kimberly, S.K. Gross, and R.M. Hughes. 1989. Rapid Bioassessment Protocols For Use In Streams and Rivers: Benthic Macroinvertebrates and Fish. U.S. Environmental Protection Agency, Office of Water, Washington D.C. pp. 1-2, 2-1.

Potts, R., L. Thorsteinson, R. Kavanagh, D. Taylor, and N. Deschu. 1993. Long-Term Ecological Monitoring Proposal, Natural Resources Inventory and Monitoring Initiative, Katmai National Park and Preserve, NPS Natural Resources Division, Alaska Regional Office, Anchorage, AK. 35 pp.

Prowse, T.D. and R.L. Stephenson, R.L. 1986. The Relationship Between Winter Lake Cover, Radiation receipts and the Oxygen Deficit in Temperate Lakes. Atmos.-Ocean 24:386-403.

Prowse, T.D. 1994. Environmental Significance of Ice to Streamflow in Cold Regions. Freshwat. Biol. 32:241-259.

Richey, J.E., M.A. Perkins, and C.R. Goldman. 1975. Effects of Kokanee Salmon (*Onchorhynchus nerka*) Decomposition on the Ecology of a Subalpine Stream. Jour. Fish. Res. Board Canada. 32:129-139.

Rosgen, D. 1996. Applied River Morphology: Wildland Hydrology. Pagosa Springs, Colorado. p. 6-14

Rouse, W.R., M.S.V. Douglas, R.E. Hecky, A.E. Hershey, G.W. Kling, L. Lesack, P. Marsh, M. McDonald, B.J. Nicholson, N.T. Roulet, and J.P. Smol. 1997. Effects of Climate Change on the Freshwaters of Arctic and Subarctic North America. [In] M.G. Anderson, N.E. Peters, D. Walling (eds.), Hydrological Processes. 2:873-902.

Schindler, D.W. 1997. Widespread Effects of Climatic Warming on Freshwater Ecosystems in North America. [In] M.G. Anderson, N.E. Peters, D. Walling (eds.), Hydrological Processes. 2:1043-1067.

Schoch, C. 1993. 1992 Stranded Oil Persistence Study on Kenai Fjords National Park and Katmai National Park and Preserve, Interim Status Report. Coastal Programs Division, National Park Service, Alaska Regional Office. Anchorage, AK.

Sease, J.L. and Loughlin. 1999. Aerial and land-based surveys of Steller sea lions (*Eumetopias jubatus*) in Alaska, June and July 1997 and 1998. Department of Commerce, National Marine Fisheries Service, Alaska Fisheries Science Center. NOAA Tech. Memorandum NMFS-SFSC-100.

Sherman, R. 1998. Personal Communication. Acting Chief, Maintenance Division. Katmai National Park and Preserve, King Salmon, AK.

Smith, T.N. and G.W. Petering. 1981. Petroleum Potential of Shelikof Strait Based on Outcrops in Katmai National Monument, Alaska. AAPG Bulletin 65(5):994.

Smith, W.R. 1925. The Cold Bay-Katmai District [In] Brooks. Mineral Resources of Alaska: U.S. Geol. Survey Bull. 773:206.

State of Alaska. 1984. Resource Management Recommendations for Katmai National Park and Preserve and Surrounding Area. Anchorage, AK. 4 p.

Stone, D.B. 1983. Present Day Plate Boundaries in Alaska and the Arctic. Jour. Alaska Geol. Soc. Proceedings of the 1982 Symposium, Western Alaska Geology and Resource Potential. Anchorage, AK. p. 3.

Trenberth, K.E. 1997. Global Warming: Its Happening. National Center for Atmospheric Research. [In] Natural Science vol.1, article 9. 10 pp.

Tucker, D. 1999. Personal Communication. Computer Programmer-Analyst, National Park Service, Water Resources Division, Fort Collins, CO.

U.S. Department of the Interior. 1952. Alaska, A Reconnaissance Report on the Potential Development of Water Resources in the Territory of Alaska for Irrigation, Power, Production and Other Beneficial Uses. U.S. Bureau of Reclamation, Alaska District Office. House Document 197, 82nd Congress. pp. 160-163.

U.S. Department of the Interior. 1970. Kodiak Oil Pollution Incident, February-March 1970, Summary Report. Federal Water Quality Administration, Washington D.C. 10 p.

U.S. Department of the Interior. 1998. Water Resources in the Final Frontier: A Strategic Plan for Department of the Interior Waters in Alaska. Department of the Interior Bureaus in Alaska (USGS, NPS, BLM, BIA, MMS). Anchorage, AK. 61 pp.

U.S. Environmental Protection Agency. 1995. Lake and Reservoir Bioassessment and Biocriteria May 12 draft document. Assessment and Watershed Protection Division, Office of Water. Washington D.C.

U.S. Fish and Wildlife Service. 1998a. National Wetlands Inventory Status – Alaska. http://www.nwi.fws.gov/images/reg7web.gif.

U.S. Fish and Wildlife Service. 1998b. Endangered, Threatened and Candidate Species in Alaska. http://www.r7.fws.gov/es/list96.html.

U.S. Geological Survey. 1997. National Water-Quality Assessment Program, Cook Inlet Basin, Alaska. USGS Fact Sheet FS-153-97. Anchorage, AK. 4 pp.

U.S. Geological Survey. 1999a. National Atlas of the United States. http://www-atlas.usgs.gov/scripts/start.html.

U.S. Geological Survey. 1999b. National Water-Quality Assessment Program, Alaska. http://www-water-ak.usgs.gov/Projects/nawqa.html.

U.S. National Park Service. 1990. National Park Service 1989 Response, Exxon Valdez Oil Spill. National Park Service, Alaska Regional Office. Anchorage, AK. 22 pp.

U.S. National Park Service. 1992. Katmai National Park and Preserve, Alaska. Visitor Brochure. Government Printing Office, 321-248/40177.

U.S. National Park Service. 1993. Trip Report for Travel by Mark Flora and David Sharrow to Katmai National Park and Preserve, July 26 to August 1, 1993 (Memorandum). NPS Water Resources Division. Ft. Collins, CO. 7 pp.

U.S. National Park Service. 1994. Resource Management Plan, Katmai National Park and Preserve. 324 pp.

U.S. National Park Service. 1997. Environmental Assessment for the Corrective Action Plan for Underground Fuel Contamination at Brooks Camp, Katmai National Park & Preserve, Alaska. Katmai National Park & Preserve, Alaska System Support Office. Anchorage, AK. 78 pp.

U.S. National Park Service. 1998a. National Park Service Procedural Manual 77-1: Wetland Protection, Technical Report NPS/NRWRD/NRTR-98/203. National Park Service, Water Resources Division, Ft. Collins, CO. 32 pp.

U.S. National Park Service. 1998b. Wetlands Mapping of the Katmai National Park Coast. NPS Project Statement (KATM-N-009.1, -021.1) prepared for FY98 Unified Call. National Park Service, Alaska Regional Office, Anchorage, AK. 7 pp.

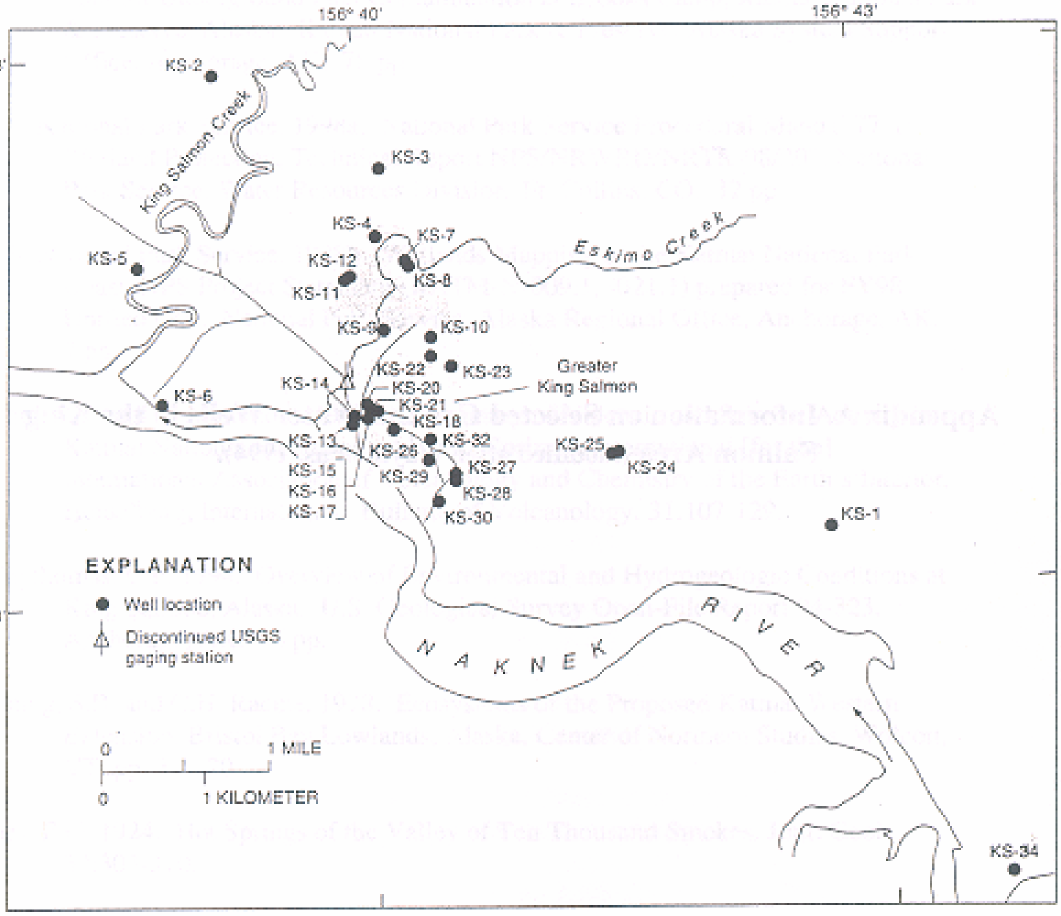
Ward, P.L. and T. Matumoto. 1967. A Summary of Volcanic and Seismic Activity in Katmai National Monument, Alaska. Springer International [for the] International Association of Volcanology and Chemistry of the Earth's Interior. Heidelberg, International. Bulletin of Volcanology. 31:107-129.

Waythomas, C.F. 1994. Overview of Environmental and Hydrogeologic Conditions at King Salmon, Alaska. U.S. Geological Survey Open-File Report 94-323. Anchorage, AK. 16 pp.

Young, S.B. and C.H. Racine. 1978. Ecosystems of the Proposed Katmai Western Extension, Bristol Bay Lowlands, Alaska. Center of Northern Studies, Wolcott, VT. pp. 3-4, 20.

Zies, E.G. 1924. Hot Springs of the Valley of Ten Thousand Smokes. Jour. Geol. 32:303-310.

Appendix A. Information on Selected Ground Water Wells in the King Salmon Area **(modified after Waythomas, 1994).**



Location of selected wells in the King Salmon area.

Information on selected water wells in the King Salmon area

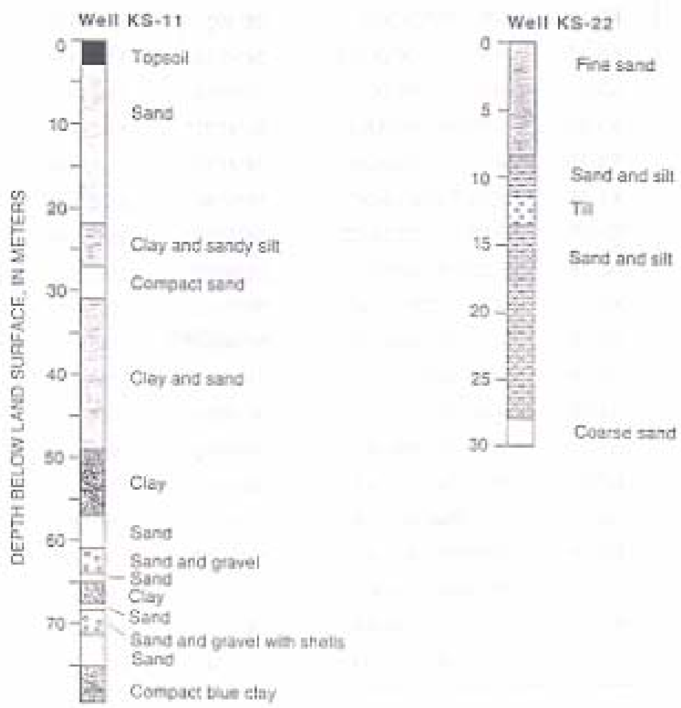
Well No.	Local well number	Location		Well depth (meters)	USGS data available	
		Latitude	Longitude		Well log	Water quality
KS-1	SC01704421 9CBDC1	58°40'19"	156°35'27"	27.6	Yes	No
KS-2	SC01704510DCCC1	58°42'42"	156°39'54"	18.3	Yes	No
KS-3	SC01704514BDDD1	58°42'16"	156°39'54"	33.9	Yes	No
KS-4	SC01704514CDDD1	58°41'50"	156°39'51"	6.0	No	No
KS-5	SC01704522BBBC1	58°41'44"	156°42'16"	24.3	Yes	No
KS-6	SC01704522CCAB1	58°41'08"	156°42'03"	66.0	Yes	Yes
KS-7	SC01704523ABAC1	58°41'43"	156°39'32"	32.4	Yes	No
KS-8	SC01704523ABAC2	58°41'43"	156°39'32"	17.1	Yes	No
KS-9	SC01704523ACCB1	58°41'28"	156°39'33"	42.3	Yes	Yes
KS-10	SC01704523ADCC1	58°41'26"	156°39'17"	51.3	Yes	No
KS-11	SC01704523BACD1	58°41'40"	156°40'05"	68.4	Yes	Yes
KS-12	SC01704523BACD2	58°41'39"	156°40'03"	71.1	Yes	Yes
KS-13	SC01704523CDCA1	58°41'03"	156°40'06"	45.9	No	No
KS-14	SC01704523CDCB1	58°41'01"	156°40'11"	32.4	Yes	Yes
KS-15	SC01704523CDCB2	58°41'01"	156°40'11"	29.1	Yes	No
KS-16	SC01704523CDCB3	58°41'03"	156°40'11"	29.4	No	Yes
KS-17	SC01704523CDCD1	58°40'57"	156°40'10"	18.0	No	No
KS-18	SC01704523CDDC1	58°40'58"	156°39'59"	28.8	No	No
KS-19	SC01704523CDDC2	58°40'59"	156°39'59"	51.6	No	No
KS-20	SC01704523CDDD1	58°40'58"	156°39'51"	28.5	No	Yes
KS-21	SC01704523CDDD2	58°40'56"	156°39'52"	42.3	Yes	No
KS-22	SC01704523DABB1	58°41'21"	156°39'19"	29.1	Yes	Yes
KS-23	SC01704523DADB1	58°41'13"	156°39'09"	33.9	Yes	Yes
KS-24	SC01704525BBDC1	58°40'46"	156°38'42"	68.7	Yes	Yes
KS-25	SC01704525BBDC2	58°40'46"	156°38'41"	18.0	No	No
KS-26	SC01704526ABBB1	58°40'53"	156°39'45"	18.4	Yes	No
KS-27	SC01704526ADAC1	58°40'40"	156°39'11"	34.2	Yes	No
KS-28	SC01704526ADAC2	58°40'40"	156°39'11"	70.8	Yes	Yes
KS-29	SC01704526ADBA1	58°40'42"	156°39'13"	45.6	Yes	No
KS-30	SC01704526ADCB1	58°40'36"	156°39'20"	27.3	Yes	No
KS-31	SC01704526BABB1	58°40'56"	156°40'10"	25.5	No	Yes
KS-32	SC01704526BBAB1	58°40'55"	156°40'10"	17.4	Yes	No
KS-33	SC01704604BBBB1	58°44'22"	156°53'47"	26.1	Yes	No
KS-34	SC01804404CCAC1	58°38'28"	156°33'46"	50.1	Yes	Yes
KS-35	SC01704523ADCC2	58°41'26"	156°39'17"	19.5	No	No
KS-36	SC01704523BBAB1	58°41'46"	156°40'22"	41.1	Yes	Yes
KS-37	SC01704526ADBA2	58°40'42"	156°39'13"	--	Yes	No

Selected chemical analyses of water from wells KS-11 and KS-22, King Salmon

[Data in milligrams per liter unless otherwise indicated. µS/cm at 25 °C, microsiemens per centimeter at 25 degrees Celsius; --, not reported]

Constituent or property	Well KS-11 Date water sample collected			Well KS-22 Date water sample collected		
	Sept. 15, 1955	April 7, 1965	May 5, 1972	Sept. 14, 1955	April 7, 1965	May 5, 1972
Specific conductance (µS/cm at 25 °C)	128	319	298	157	123	119
pH (units)	7.5	8.1	8.3	7.9	7.6	7.4
Hardness as $CaCO_3$ (Ca, Mg)	47	26	16	46	50	52
Noncarbonate hardness	0	0	0	0	1	5
Calcium (Ca)	8.3	5.6	3.8	8.3	8.8	12
Magnesium (Mg)	6.4	2.9	1.6	6.2	6.8	5.4
Sodium (Na)	6.8	70	60	15	5.9	5.4
Potassium (K)	3.5	7.8	5.1	4.5	5.1	2.9
Bicarbonate (HCO_3)	70	210	170	90	60	56
Sulfate (SO_4)	4.5	3.4	2.6	3	13	12
Chloride (Cl)	0	--	10	5	4.6	4.2
Fluoride (F)	0	.3	.2	0	.2	.1
Silica (SiO_2)	19	34	33	19	39	39
Dissolved solids, calculated (mg/L)	83	239	200	105	113	109
Dissolved solids, calculated (tons per acre-foot)	.11	.33	.27	.14	.15	.15
Nitrate (NO_3)	.1	.6	.1	.1	.3	.1
Iron (Fe)	35	20	--	280	150	--

Drillers' logs for wells KS-11 and KS-22.



Appendix B. List of Reviewers

The following individuals provided valuable input during the review process of this report.

Participant	Representing
John Bundy	NPS-Katmai National Park and Preserve
Rick Clark	NPS-Katmai National Park and Preserve
Nancy Deschu	NPS-Alaska Support Office
Mark Flora	NPS-Water Resources Division
Troy Hamon	NPS-Katmai National Park and Preserve
Bill Hansen	NPS-Water Resources Division
Ross Kavanagh	NPS-Alaska Support Office
Deb Liggett	NPS-Katmai National Park and Preserve, and Lake Clark National Park and Preserve
Barry Long	NPS-Water Resources Division
David Sharrow	NPS-Zion National Park (former WRD employee)
Jim Tilmant	NPS-Water Resources Division
David Vana-Miller	NPS-Water Resources Division